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**FINAL BASIS OF DESIGN FOR PHASE I  
INTERIM REMEDIAL ACTION**

**OPERABLE UNIT NO. 10  
SITE 35 - CAMP GEIGER AREA FUEL FARM  
MARINE CORPS BASE  
CAMP LEJEUNE, NORTH CAROLINA**

**CONTRACT TASK ORDER 0323**

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*Prepared for:*

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## **1.0 INTRODUCTION**

This document presents the Basis of Design for an interim remedial action (IRA) for contaminated groundwater at Operable Unit No. 10, Site 35, Camp Geiger Area Fuel Farm, Marine Corps Base (MCB), Camp Lejeune, North Carolina. This document has been prepared by Baker Environmental, Inc. (Baker) for presentation to the Department of the Navy (DoN), Naval Facilities Engineering Command, Atlantic Division (LANTDIV), under Navy CLEAN Contract Number N62470 (Contract Task Order 0323), and in accordance with LANTDIV's Scope of Work dated June 27, 1995.

The DoN is in the process of implementing an overall remedial action (RA) at the Site 35 as part of the Installation Restoration (IR) Program for MCB Camp Lejeune. The overall RA will focus on the remediation of contaminated groundwater in the surficial aquifer, based on alternatives presented in the Draft Feasibility Study (FS) for Operable Unit No. 10, Site 35 (Baker, 1997).

This Basis of Design presents the approach for an IRA for Site 35 which focuses on an area of groundwater contamination along the southern boundary of the proposed U.S. Highway 17 Bypass right-of-way. Since this represents only a portion of the contaminated shallow groundwater identified at the site, this action is referred to as an "interim" remedial action. That is, it represents only a portion of a more comprehensive remedial action for Site 35, and will not necessarily be the final overall solution for the site. The selected technology for the IRA is in-situ air sparging (IAS). This Basis of Design, and the associated plans and specifications, present information on the initial phase (Phase I) of the IRA. The data collected during the Phase I IRA will be used to determine the scope for the continuation of the IRA and possible extension of the IAS system.

LANTDIV intends to use a Remedial Action Contractor (RAC) to implement this remedial action. In this document, the terms "RAC" and "Contractor" are used interchangeably. A construction cost estimate for the project is provided in Appendix A.

### **1.1 Objectives of the IRA**

The objectives of Phase I of the IRA are as follows:

- Assess the applicability of IAS technology in addressing shallow groundwater contamination at Site 35 by evaluating the effectiveness, implementability, and costs of a full-scale treatment system.
- Obtain sufficient data to afford the development of a full-scale system remedial design.
- Assess the impact of air emissions on human health and the environment, and verify that air emissions will not impact the proposed highway project.

After the Phase I IRA has been installed, its performance will be evaluated and adjustments or improvements will be recommended for the continuation of the IRA (i.e., Phase II).

The work presented in this report, and in the plans and specifications, will be performed in a phased approach and will require that the Contractor obtain input and concurrence from the DoN before



proceeding to the next phase. The intermediate steps in this process are presented in the specifications.

## **1.2 Purpose of the Basis of Design**

The purpose of the Basis of Design is to present LANTDIV with background data on the project, describe the primary elements of the Phase I IRA design, recommend design criteria, and present assumptions and any special requirements that may affect the IRA. This document is not intended to be part of construction plans or specifications to be utilized by the RAC for execution of the IRA. Baker assumes no responsibility for the use of this report for any purpose other than the intended uses stated above.

## **2.0 SITE BACKGROUND INFORMATION**

The following sections provide site background information relevant to the proposed IRA including site description and history, previous investigations, site geology and hydrogeology, nature and extent of contamination, groundwater remediation goals, and areas of concern for groundwater.

### **2.1 Site Location and Description**

Camp Lejeune (also referred to as the "Activity") is located in Onslow County, North Carolina (Figure 2-1). The Activity currently covers approximately 234 square miles and is bisected by the New River, which flows in a southeasterly direction and forms a large estuary before entering the Atlantic Ocean. The west and northwest borders of the Activity are defined by U.S. Route 17 and State Route 24, respectively. The eastern border is defined by the Atlantic Ocean shoreline while the City of Jacksonville, North Carolina, borders the Activity to the north.

Camp Geiger is located at the extreme northwest corner of Camp Lejeune and contains a mixture of troop housing, personnel support and training facilities. The main entrance is located along U.S. Route 17, approximately 3.5 miles southeast of the City of Jacksonville, North Carolina. Camp Geiger is roughly bounded by Brinson Creek to the north and northeast, an abandoned Seaboard Railroad right-of-way to the east, Curtis Road to the south, and U. S. Route 17 to the west.

Site 35, Camp Geiger Area Fuel Farm refers to a former fuel storage and dispensing facility that was located just north of the intersection of Fourth and "G" Streets, prior to its demolition in the spring of 1995. The facility consisted primarily of five, 15,000-gallon aboveground storage tanks (ASTs), a pump house, a fuel loading/unloading pad, an oil/water separator, and a distribution island (Figure 2-2).

The Phase I IRA will be implemented in an area located along the southern boundary of the proposed U.S. Highway 17 Bypass right-of-way, immediately south of the former Fuel Farm, and north of the intersection of Fourth and "G" Streets (Figure 2-2).

### **2.2 Site History**

Construction of Camp Lejeune began in 1941 with the objective of developing the "Worlds Most Complete Amphibious Training Base." Construction started at Hadnot Point, where the major functions of the Activity are centered. Development at the Activity is primarily in five geographical locations under the jurisdiction of the Base Command. These areas include Camp Geiger, Montford Point, Courthouse Bay, Mainside, and the Rifle Range Area.

Construction of Camp Geiger was completed in 1945, four years after construction of Camp Lejeune was initiated. Originally, the Fuel Farm ASTs were used for the storage of No. 6 fuel oil. An underground distribution line (now abandoned) extended from the ASTs to the former Mess Hall Heating Plant, located adjacent to "D" Street, between Third and Fourth Streets. The underground line dispensed No. 6 fuel oil to a UST which fueled the Mess Hall boiler. The Mess Hall, located across "D" Street to the west, is believed to have been demolished along with its Heating Plant in the 1960s. At some unrecorded date the Fuel Farm was converted for storage of other petroleum products, including unleaded gasoline, diesel fuel, and kerosene.

From the date of this conversion until the facility was decommissioned in the spring of 1995 the ASTs at Site 35 were used to dispense gasoline, diesel and kerosene to government vehicles, and to supply underground storage tanks (USTs) in use at Camp Geiger and the nearby New River Marine Corps Air Station. The ASTs were supplied by commercial carrier trucks which delivered product to fill ports located on the fuel loading/unloading pad located south of the ASTs. Six, short-run (120 feet maximum), underground fuel lines were utilized to distribute the product from the unloading pad to the ASTs.

During the lifetime of the facility several releases of product occurred. Reports of a release from an underground distribution line near one of the ASTs date back to 1957-58 (ESE, 1990). Apparently, the leak occurred as the result of damage to a dispensing pump. At that time the Camp Lejeune Fire Department estimated that thousands of gallons of fuel were released although records of the incident have since been destroyed. The fuel reportedly migrated to the east and northeast toward Brinson Creek. Interceptor trenches were excavated and the captured fuel was ignited and burned.

Routinely, the ASTs at Site 35 supplied fuel to an adjacent dispensing pump that was supplied by an underground line. A leak in an underground line at the station was reportedly responsible for the loss of roughly 30 gallons per day of gasoline over an unspecified period (Law, 1992). The leaking line was subsequently sealed and replaced.

In April 1990, an undetermined amount of fuel was discovered by Camp Geiger personnel along two unnamed drainage channels north of the Fuel Farm. Apparently, the source of the fuel, believed to be diesel or jet fuel, was an unauthorized discharge from a tanker truck that was never identified. The Activity reportedly initiated an emergency clean-up which included the removal of approximately 20 cubic yards of soil.

The Fuel Farm was decommissioned and demolished during the spring of 1995. The ASTs were emptied, cleaned, dismantled, and removed along with all concrete foundations, slabs on grade, berms and associated underground piping. The Fuel Farm was demolished to make way for the U.S. Highway 17 Bypass.

In addition to the Fuel Farm dismantling, soil remediation activities were executed between the spring of 1995 and the spring of 1996 along the proposed U.S. Highway 17 Bypass right-of-way as directed by the Interim Remedial Action Record of Decision for Petroleum Hydrocarbon Contaminated Soil, that was executed on September 15, 1994.

### **2.3 Previous Investigations**

The purpose of this section is to summarize existing information pertaining to previous environmental studies involving Site 35. Information presented herein can be found in the: Initial Assessment Study of Marine Corps Base, Camp Lejeune, North Carolina (WAR, 1983), Final Site Summary Report, MCB Camp Lejeune (ESE, 1990); Draft Field Investigation/Focused Feasibility Study, Camp Geiger Fuel Spill Site (NUS, 1990), Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1992); the Addendum Report of Underground Fuel Investigation and Comprehensive Site Assessment (Law, 1993); the Interim Remedial Action Remedial Investigation/Feasibility Study for Soil (Baker, 1994); Remedial Investigation Report (RI) (Baker, 1995a); Interim Feasibility Study for Shallow Groundwater in the Vicinity of the Former Fuel Farm (Interim FS) (Baker, 1995b); Supplemental Groundwater Investigation (SGI) (Baker, 1996a); In-Situ Air Sparging Treatability Study (IAS Treatability Study) (Baker, 1996b); and Draft

Feasibility Study (FS) (Baker, 1997). The reports that were used to support the development of this Basis of Design are summarized in this section and include the: RI; Interim FS; SGI; IAS Treatability Study; and Draft FS. The areas associated with these reports are shown in Figure 2-2.

### **2.3.1 Remedial Investigation**

Site-wide, comprehensive Remedial Investigation field activities were initiated by Baker in April 1994. The purpose of these activities was to provide additional data in order to assess the impact on aquatic and benthic species in Brinson Creek, support a site-wide risk assessment, determine the full nature and extent of halogenated organic contamination in the surficial aquifer, and support an Interim FS. Field activities included the following: a soil gas and groundwater screening investigation; a soil investigation; a groundwater investigation; a surface water/sediment investigation; and an ecological investigation.

In general the results were as follows:

- There were relatively few detection of VOCs and semivolatile organic compounds (SVOCs) in the subsurface and surface soil samples. Pesticides were detected in surface soil, but were not deemed to be site related.
- Extensive organic groundwater contamination was observed in both the upper and lower portions of the surficial aquifer. However, the extent of solvent-related contamination in the lower portion of the surficial aquifer appeared to extend beyond the southern limits of the RI, and was, therefore, not adequately defined.
- The northeastern edge of the solvent-related groundwater contamination plume was not delineated. From the RI data it was impossible to determine if Brinson Creek was acting as a hydraulic barrier to groundwater contamination migrating off-site onto Onslow County property.
- Elevated levels of inorganic contaminants were also detected in groundwater samples collected from the surficial aquifer and appeared to be due to the sampling methods used.
- Significant levels of organic and inorganic contamination were detected in the sediment samples. However, some problems were experienced with this data. Detections of organic contamination were masked by a high number of tentatively identified compounds (TICs) and some inorganic data was rejected by professional data validators. Surface water contamination was limited to a single detection of lead and zinc at a sampling location downstream of Site 35.
- The human health risk associated with Site 35 was determined to be in excess of the acceptable range. The total risk was driven by future potential exposure to groundwater and current potential exposure to fish.
- The ecological risk assessment determined that there were no significant adverse impacts to terrestrial receptors from site-related contaminants.

### **2.3.2 Interim Remedial Action Feasibility Study for Shallow Groundwater in the Vicinity of the Former Fuel Farm**

The purpose of the Interim FS (Baker, 1995b) was to identify and evaluate various remedial actions for contaminated shallow groundwater in the vicinity of the Fuel Farm at Site 35. The Interim FS was intended to develop potential remedial actions that were to provide for the protection of human health and the environment from contaminated groundwater in this area prior to the completion of a comprehensive FS, that was to consider remedial actions for the entire area of contaminated groundwater as well as other media.

Ultimately, five Remedial Action Alternatives (RAAs) were developed to prevent the migration of fuel and solvent-related groundwater contamination into Brinson Creek. These RAAs included:

- RAA 1 - No Action
- RAA 2 - No Action With Institutional Controls
- RAA 3 - Groundwater Collection and On-Site Treatment
- RAA 4 - In-Situ Air Sparging and Off-Gas Carbon Adsorption
- RAA 5 - In-Well Aeration and Off-Gas Carbon Adsorption

#### **2.3.2.1 Post Interim FS Activities**

The Interim FS culminated with the execution of the "Interim ROD For Surficial Groundwater for a Portion of Operable Unit No. 10 - Camp Geiger Fuel Farm," signed on September 5, 1995. The Interim ROD detailed the five RAAs described in the Interim FS for the remediation of organic contamination of the surficial aquifer. RAA 5, In-Well Aeration with Off-Gas Carbon Adsorption, was selected as the preferred remedy in the Interim ROD, contingent upon the successful execution of preliminary field pilot-scale tests.

The Interim ROD indicated the viability of in-well aeration was to be determined by means of a field pilot test that was to have been initiated in September 1995. However, the pilot test at Site 69 experienced substantial delays and is anticipated to be completed in 1997. The results of this test will determine the viability of in-well aeration at Camp Lejeune. The Interim ROD prescribed RAA 3, Groundwater Collection and On-Site Treatment, to be substituted as the preferred remedy in the event in-well aeration could not be implemented.

In August 1996, the EPA, NC DEHNR, LANTDIV, Camp Lejeune, and Baker considered the delays to the in-well aeration pilot test and agreed that a treatability study employing in-situ air sparging would be appropriate at this site to evaluate this technology as a possible alternative to those presented in the Interim ROD. Baker performed an IAS Treatability Study in August 1996. The results of this treatability study and recommendations are discussed in Section 2.3.4.

### **2.3.3 Supplemental Groundwater Investigation**

SGI field activities were performed by Baker during August, 1995 and April through November, 1996. The purpose of these activities was to provide additional data in order to: determine the full nature and extent of solvent-related organic contamination in the surficial aquifer northeast of Brinson Creek and South of Fifth Street; accurately quantify total metals contamination through the use of a low-flow pumping technique; determine the extent of Total Petroleum Hydrocarbon (TPH), zinc, and mercury contamination in Brinson Creek sediments; identify any



source areas; and support the implementation of an IAS pilot study. Figure 2-2 shows the two areas considered in the SGI. Field activities included the following: a soil gas and groundwater screening investigation; a soil investigation; a groundwater investigation; and a sediment investigation.

The results of the SGI are as follows:

- The limits of the solvent-related groundwater contamination in the lower portion of the surficial aquifer were identified to a location South of Fifth Street. In general this plume extends south of Fifth Street along "C" Street from Building G534 to the intersection of "C" and Sixth Street. The edge of the plume extends from this intersection across Camp Geiger to Building TC773. At this point, the edge of the plume swings northward along the eastern tree line of Camp Geiger and continues north to Fifth Street.
- No fuel or solvent-related groundwater and soil contamination was detected in samples collected from the northeast side of Brinson Creek. Therefore, fuel and solvent-related contamination apparently has not migrated off-site onto Onslow County property.
- Samples collected using a low-flow sampling technique yielded results with lower concentrations of metals than those obtained in the RI, indicating that suspended solids may have influenced the inorganic levels observed in the RI data. Four metals (iron, manganese, aluminum, and antimony) were detected during the SGI at levels that exceed regulatory limits. Elevated levels of metal constituents in groundwater are typical of the Camp Lejeune groundwater and are generally due to geologic conditions rather than site-related contamination.
- Fuel-related contamination is widespread in Brinson Creek sediments. The highest concentrations of TPH contamination were detected downstream of Site 35. It was concluded that previous operations most likely contributed to fuel-related sediment contamination in Brinson Creek in areas adjacent to, and downstream of the former Fuel Farm.
- A limited number of sediment samples exhibited low levels of zinc and mercury. However, no records exist that would indicate these compounds were used at Site 35. It was concluded that previous operations at Site 35 most likely did not contribute to observed concentrations of mercury and zinc in Brinson Creek sediments.
- No fuel or solvent-related contamination was detected during soil screening activities at Site 35. These results indicate that the spilled solvents and fuels have probably migrated into the saturated zone and are no longer acting as a continued source in the soil.

#### **2.3.4 IAS Treatability Study**

An IAS pilot test was conducted by Baker during July and August of 1996 to assess the viability of in-situ air sparging as a possible Remedial Alternative (RA) for the remediation of shallow groundwater contamination in the vicinity of Brinson Creek at Site 35 (Figure 2-2). As part of this

study, 14 permanent monitoring wells, two air sparging wells, and six soil gas probes were installed in the wetland area along Brinson Creek approximately 500 feet to the northeast of the former Fuel Farm.

The treatability study was comprised of two tests (deep and shallow air injection) each consisting of two phases (low and high flow rates). Helium was injected with the air as a tracer gas. Prior to the start of the first test, a round of groundwater and air samples were collected from monitoring wells and soil gas probes to establish a baseline of control data. During the first test, air was injected into the deep air sparging well at a rate of 7.5 actual cubic feet per minute (acfm) for 24 hours and 20 acfm for 24 hours. A post-study monitoring period lasted for 24 hours prior to initiating the second test. The second test consisted of injecting air into the shallow air sparging well at flow rates of 5 and 20 acfm. Both of these flow rates were maintained for periods of 24 hours each.

During both the first and second test, monitoring wells and soil gas probes were monitored at regular intervals for a variety of parameters to assess the impact of the injected air. Monitoring wells were monitored for static water levels, dissolved oxygen levels, and helium concentrations in the ambient air and groundwater samples were collected for laboratory analysis. Soil gas probes were monitored for oxygen, pressure, and helium concentrations of ambient air, and soil gas samples were collected for laboratory analysis.

A summary of the conclusions of the IAS Treatability Study Report are as follows:

- IAS via vertical injection would have limited effectiveness on solvent-related contaminants located at the base of the surficial aquifer. In order to remediate contaminated groundwater with IAS via vertical injection, air must be injected 4 to 6 feet below the zone of contamination. The semiconfining layer at the base of the surficial aquifer is too impermeable to allow air injection below the zone of contamination, the base of the surficial aquifer.
- IAS would be ineffective in the northeast area of the site where a large clay lens exist. The clay layer would inhibit the release of contaminants to the atmosphere and potentially cause lateral migration of the contaminants.
- Fuel-related groundwater contamination is not present in the Brinson Creek wetland area adjacent to Site 35.
- For the reasons listed above, IAS will not effectively address BTEX contamination on the northern side of the U.S. Highway 17 Bypass right-of way.

Based on these conclusion the following was recommended:

- An IAS system where air is injected horizontally along the top of the semiconfining unit is preferable to a conventional IAS system.
- Due to site access restrictions and lack of BTEX contamination in groundwater along the northern edge of the U.S. Highway 17 Bypass right-of-way, an IAS system would be more effective on the southern edge of the right-of-way.

- A pilot test should be conducted prior to the implementation of a full-scale horizontal IAS system.

The results indicated that IAS via vertical air injection wells located on the north side of the proposed U.S. Route 17 Bypass right-of-way would not impact groundwater contamination as expected. The IAS Treatability Study Report recommended the implementation of IAS via horizontal injection trenches to be located on the south side of the proposed U.S. Highway 17 Bypass right-of-way.

### **2.3.5 Feasibility Study**

The purpose of the FS (Baker, 1997) was to identify and evaluate various remedial actions for site-wide contaminated shallow groundwater at Site 35, that are protective of human health and the environment, and will attain federal and state requirements. Alternatives for the FS were developed assuming an in-situ air sparging system would be installed along the south side of the U. S. Highway 17 Bypass right-of-way to prevent the migration of fuel and solvent-related contamination into Brinson Creek.

Ultimately, six RAAs were developed for the remediation of contaminated groundwater at Site 35. These RAAs included:

- RAA 1 - No Action
- RAA 2 - Site Controls and Long-term Monitoring
- RAA 3 - Natural Attenuation
- RAA 4 - Extraction and Ex Situ Treatment
- RAA 5 - In-Situ Passive Treatment/Slurry Cut-Off Wall
- RAA 6 - In-Well Aeration and Off-Gas Carbon Adsorption

A draft Proposed Remedial Action Plan (PRAP) for Site 35 was submitted in January, 1997 (Baker, 1997). The draft PRAP detailed the five RAAs described in the FS for the remediation of organic contamination of the surficial aquifer. RAA 3, Natural Attenuation, was selected as the preferred remedy in the PRAP. This alternative provides a remedy that is protective of human health and the environment, highly implementable, and cost effective.

### **2.3.6 Pre-Interim Remedial Action Field Investigation**

The EPA, NC DEHNR, LANTDIV, Camp Lejeune and Baker concurred in November 1996, that it was appropriate to consider IAS via horizontal injection trenches along the south side of the U.S. Highway 17 Bypass right-of-way, as an alternative to vertical air injection wells on the north side of the proposed highway, and as a possible alternative to RAA 3, Groundwater Collection and On-Site Treatment. It was agreed that prior to full-scale implementation of IAS via horizontal injection trenches a field pilot-scale test (Phase I Interim Remedial Action) would be performed along the south side of the U.S. Highway 17 Bypass right-of-way. To support the design and construction of the Phase I Interim Remedial Action, site-specific data was needed. This data was obtained as part of a pre-interim remedial action field investigation conducted by Baker in February 1997. The results of this work were reported in correspondence dated June 6, 1997 (see Appendix C).

Prior to mobilizing to the site, Baker identified two potential specific locations for the Phase I construction activity. The two potential locations included a northern area (Area 1), located in the

vicinity of the former Fuel Farm and a southern area (Area 2) located between Fourth Street and Building TC473. The specific objectives of field activities to be conducted in both of these areas were as follows:

- Establish via survey, the exact location of the southern right-of-way boundary of the proposed U.S. Highway 17 Bypass in the vicinity of Site 35.
- Gather sufficient geological data to determine the elevation of the confining unit.
- Identify any clay lenses or strata that could potentially impact the design and implementation of an in-situ air sparging system.
- Determine the current levels of fuel and solvent-related groundwater contamination.

To achieve these objectives, the U.S. Highway 17 Bypass southern right-of-way boundary was staked and surveyed in the field, a total of 10 soil borings were advanced for the purpose identifying lithology and to install temporary monitoring wells, and 12 wells (10 temporary and 2 permanent) were sampled for Target Compound List (TCL) VOCs.

The general results of the field effort were as follows:

- The confining unit was identified at approximately 44 feet below ground surface (bgs) across both areas.
- No clay lenses were identified within the limits of either area.
- Fuel-related contamination was observed in the upper portion of the surficial aquifer within the limits of Area B; however, it was limited to a single detection.
- Solvent-related contamination was detected in the lower portion of the surficial aquifer at maximum level of 298 ug/L within the limits of Area 1.
- Solvent-related contamination was detected in the upper and lower portions of the surficial aquifer and ranged between 30 ug/L and 886 ug/L within the limits of Area 2.

A summary of the conclusions and recommendation is presented below:

- When compared to the results of the RI, fuel-related contamination has been impacted in both areas by the removal of petroleum contaminated soils in the vicinity of the former Fuel Farm.
- The levels of solvent-related contamination detected in both areas are generally consistent with levels detected during the RI.
- Based on contaminant levels, the optimal location of the IAS system is in Area 2.

- The delay of demolition activities associated with the proposed U.S. Highway 17 Bypass would delay Phase I construction activities in Area 2. Phase I activities could not commence in Area 2 until buildings TC-473 and TC-474, and associated parking lots are removed. Demolition of these facilities will occur as part of the U.S. Highway 17 Bypass project. However, the start of highway construction activities in the Site 35 area is uncertain.
- The delay of demolition activities associated with the proposed U.S. Highway 17 Bypass would not delay Phase I construction activities in Area 1.
- Based on the field data obtained during the field investigation and background information Baker recommended that Area 1 be selected as the location for Phase I construction activities.

## 2.4 Site Geology and Hydrogeology

In general, the upper-most soils at Site 35 are comprised of sand with lesser amounts of silt and clay. Lenses of silts and clays are present throughout the sand. Immediately below this sand are calcareous sands with varying amounts of shell and fossiliferous limestone fragments, interbedded with shell and fossiliferous limestone fragment layers. Collectively, these soils comprise what is called the undifferentiated formation, as well as the surficial aquifer.

A generally fine sand with lesser amounts of silt and clay is present immediately below the calcareous sands and shell/limestone fragment layer. This unit has been interpreted as the Belgrade Formation, or Castle Hayne Confining Unit. This unit was observed throughout the study area, typically at a depth of approximately 40 feet to 45 below ground surface (bgs). The pre-interim remedial action field investigation conducted in February, 1997 identified the depth of the confining unit at 44 feet to 46 feet bgs in the vicinity of Phase I construction activities. The soils of this unit have a distinct green, or greenish-gray color, and contain less water than the overlying soils. This unit was observed to be seven to 12 feet thick.

A fine to medium sand with lesser amounts of shell fragments, silt, and clay is present immediately below the Castle Hayne Confining Unit. This unit has been interpreted as the River Bend Formation, or the upper portion of the Castle Hayne Aquifer.

A geologic cross-section was constructed from the boring logs of four monitoring wells, MW-14, -15, -22, and -27, that are generally located in the general vicinity of the proposed Phase I Interim Remedial Action (Figure 2-3). These boring logs were obtained from the Underground Fuel Investigation And Comprehensive Site Assessment (Law, 1992). The cross-section extends approximately 345 feet from MW-14 located immediately north of the former gas station to MW-27 located near building TC474, and depicts subsurface soil conditions to a depth of -19.5 feet mean sea level (msl) or approximately 35 feet below ground surface (bgs). As illustrated in Figure 2-4 the upper strata of soil underlying this area consists of fine to medium sands, silty sand, and lenses of clayey silt and silty clay. The lower stratum of soil consists of a medium sand with shell fragments, and is characterized in the Law, 1992 report as the River Bend formation. However, Baker boring logs from nearby monitoring wells indicate the presence of the Castle Hayne confining unit, which is above the River Bend formation, at a depth of 40 - 45 feet bgs. A cross-section constructed from borings advanced along the southern right-of-way boundary is provided in the pre-interim remedial action letter report.



Groundwater was encountered at varying depths during the RI and SGI drilling programs. This variation is primarily attributable to topographic changes. In general, the groundwater was encountered between 5.5 and 8.5 feet bgs. The water table nears the ground surface in the area of Brinson Creek, where the topographic elevation decreases.

The direction of surficial aquifer groundwater flow in the vicinity of Site 35 is to the northeast, toward Brinson Creek. The groundwater flow gradient in July 1996 was approximately 0.007 feet/foot and 0.017 feet/foot in September 1994. Groundwater in the surficial aquifer appears to discharge to Brinson Creek based on the groundwater flow direction, the relative elevations of the creek, the ground surface elevations, and the groundwater potentiometric surface.

The average surficial aquifer (lower portion) hydraulic conductivity values calculated for the SGI study are on the same order of magnitude as the value in Cardinell, et al., 1993. The average hydraulic conductivity of the falling head slug tests conducted on wells constructed during the SGI is 89.5 feet/day. This is slightly higher, but comparable to the Cardinell value of 50 feet/day (Cardinell, et., al., 1993). The average hydraulic conductivity of falling head tests conducted on wells constructed during the RI was 5.16 feet/day, approximately an order of magnitude less. These results indicate that the surficial aquifer in the southern area of Site 35 has a higher hydraulic conductivity than the northern area.

Additional information, geological cross sections, boring logs, and slug test data can be found in the RI (Baker, 1995) and SGI (Baker, 1997) Reports.

## **2.5 Nature and Extent of Contamination**

Extensive groundwater contamination was observed in the surficial aquifer along both the upper and lower monitored intervals. Fuel-related contaminants were more prevalent in the upper portion of the surficial aquifer and solvent-related contaminants were more prevalent in the lower portion of the surficial aquifer. The data gathered during the RI (Baker, 1995) was able to adequately define the extent of both fuel and solvent-related contamination in the upper portion of the surficial aquifer (Figures 2-5 and 2-6), and fuel-related contamination in the lower portion of the surficial aquifer (Figure 2-7). More recent site specific data is provided in the pre-interim remedial action field investigation letter report (Appendix C).

Fuel-related contamination, based on RI data, in both the upper and lower portion of the surficial aquifer is generally limited to an area north of Fifth Street and east of barracks G532-G534. Suspected sources were the former Fuel Farm, and nearby former UST sites located near building G480 and the former Mess Hall Heating Plant. Since that investigation the potential source areas of fuel-related groundwater contamination have been removed.

Solvent-related contamination in the upper portion of the surficial aquifer, identified during the RI, is also generally located in an area north of Fifth Street and east of barracks G532-G534. Suspected sources appear to be located near Building G480, north of the Fuel Farm and in the vicinity of building TC474.

The RI data did not define the extent of solvent-related contamination in the lower portion of the surficial aquifer south of Fifth Street or on the northeast side of Brinson Creek. However, data gathered during the SGI established the southern extent of solvent-related contamination in the lower

portion of the surficial aquifer and indicated no site related groundwater contamination had migrated off-site onto Onslow County property located on the northeast side of Brinson Creek (Figure 2-8).

Figure 2-8 depicts the full extent of solvent-related contamination in the lower portion of the surficial aquifer and is based primarily on SGI data. Solvent-related contamination in the lower portion of the surficial aquifer extends from north of Fourth Street to Eighth Street, and from Brinson Creek and the Camp Geiger tree line, west, to "C" Street. The highest concentrations of solvent-related contamination in the lower portion of the surficial aquifer are centered at the intersection of "E" and Fourth Streets, and in the vicinity of Building TC474, the former Vehicle Maintenance Garage.

The area of solvent-related contamination identified in the vicinity of building TC474, and depicted on Figure 2-8 was based on RI data. It was included to demonstrate potential problems that would be encountered by locating the Phase I, Interim Remedial Action in vicinity of Building TC474. The area of high solvent-related contamination, associated with Building TC474, located along the southern boundary of U.S. Highway 17 Bypass right-of-way, is under active roadways, parking lots and buildings. Although these facilities are scheduled for demolition as part of the U.S. Highway 17 Bypass construction, a completion date for the completion of demolition work could not be provided by the North Carolina Department of Transportation (NCDOT). The contract for the construction of U.S. Highway 17 Bypass is scheduled to be awarded in the spring of 1997. It should be noted that the U.S. Highway 17 Bypass project has experienced delays in the past.

In order, to minimize delays and potential conflicts with existing facilities or future construction activities the recommended location of the Phase I Interim Remedial Action will be in the vicinity of the former Fuel Farm.

## **2.6 Area of Concern**

The area of concern associated with Site 35 and shown on Figure 2-9 was developed using RI and SGI data, and is a combination of fuel and solvent-related groundwater contamination data from the upper and lower portion of the surficial aquifer. Groundwater in the surficial aquifer (upper and lower portion) within the limits of this area of concern contains levels of Contaminant of Concern (COCs) that exceed regulatory limits. Groundwater contamination outside the limits of the area of concern is below regulatory limits.

The area of concern associated with the overall IRA extends along the southern right-of-way boundary of the proposed U.S. Highway 17 Bypass, approximately 1,150 feet, from Third Street to the recently constructed pump station. Phase I of the IRA will be located within these limits.

## **2.7 Remediation Goals**

In accordance with Section 121(d)(1) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), remedial actions must attain a degree of cleanup which assures protection of human health and the environment. Although groundwater within the limits of the contaminant plume site is not currently used as a source of potable water, results of the human health risk assessment performed under RI, and modified by a supplemental human health risk assessment performed under the SGI, indicated that the ingestion and dermal exposure to groundwater poses a risk to future residents.

Groundwater remediation goals for the contaminants of concern, as identified in the human health risk assessments performed under RI and SGI, were developed as a part of the Draft FS (Baker, 1997). These remediation goals are presented in Table 2-1.

**TABLE 2-1**

**GROUNDWATER REMEDIATION GOALS  
OU NO. 10, SITE 35 - CAMP GEIGER AREA FUEL FARM  
PHASE I, INTERIM REMEDIAL ACTION BASIS OF DESIGN, CTO-0323  
MCB, CAMP LEJEUNE, NORTH CAROLINA**

Contaminant of Concern	Remediation Level (µg/L)	Basis
Benzene	1	NCWQS
cis-1,2-Dichloroethene	70	NCWQS
Ethylbenzene	29	NCWQS
Methyl Tertiary Butyl Ether	200	NCWQS
trans-1,2-Dichloroethene	70	NCWQS
1,2-Dichloroethene	70	MCL
Trichloroethene	2.8	NCWQS
Tetrachloroethene	0.7	NCWQS
1,1,2,2-Tetrachloroethane	0.41	Risk-based RGO <sup>(1)</sup>
Xylenes (total)	530	NCWQS
Vinyl Chloride	0.015	NCWQS

Note:

- <sup>(1)</sup> Based on a carcinogenic target risk level of  $1 \times 10^{-6}$ . The equation used to calculate this RGO is based on guidance in USEPA Region IV Bulletin, November 1995.

### **3.0 PHASE I AIR SPARGING DESIGN AND PERFORMANCE REQUIREMENTS**

The proposed Phase I IRA at Site 35 will, by design, impact only a portion of the contaminated shallow groundwater identified at the site. Consequently, this action is referred to as an "interim" remedial action. That is, it represents only a portion of a more comprehensive remedial action for Site 35, and will not necessarily be the final solution for OU No. 10. In addition, this Basis of Design focuses on the initial phase, or Phase I, of the interim remedial action.

This section presents background information on IAS technology, discusses system design, performance and monitoring requirements. Special conditions that will need to be considered during implementation of the Phase I system are also presented.

#### **3.1 Air Sparging**

In-situ air sparging (IAS) technology has been selected for the IRA to address the shallow groundwater contamination at Site 35. This technology addresses VOC contamination via in situ (in place) remediation. IAS is used for groundwater remediation and essentially acts as a "subsurface air stripper" to volatilize dissolved VOCs from the groundwater. The primary components of the IAS system include air sparging wells and an air compressor. Figure 3-1 provides a schematic process flow diagram that illustrates the primary components of the IAS system. For larger systems, or for long-term projects, a building may be required to house the various mechanical/electrical components of the system. Otherwise, systems can be skid-mounted or housed in trailers. A description of the IAS technology is provided in the Interim FS (Baker, 1995), the IAS Treatability Study Report (Baker, 1996), and "Air Sparging in Gate Wells in Cutoff Walls and Trenches for Control of Plumes of Volatile Organic Compounds (VOCs)" (Pankow, et al., 1993), which is provided in Appendix B.

The IAS process involves injection of air into a water table aquifer to create a "subsurface air stripper" that volatilizes dissolved contaminants. In addition to volatilizing contaminants, natural aerobic biodegradation processes can be enhanced by this process due to the addition of air and oxygen to the aquifer.

IAS systems have been successfully applied at a number of sites. The correct design and operation of these systems in favorable geologic settings have successfully achieved groundwater cleanup to relatively low cleanup levels. However, incorrect design or application of these systems or implementation in unfavorable geologic settings (i.e., low permeable formations or lenses) can result in undesirable contaminant migration in both the dissolved and vapor phases.

A typical IAS system will utilize a network of air injection points constructed of small-diameter wells or well points installed to below the zone of contamination. The well points are spaced such that they have overlapping zones of influence. Air is injected into the well and exits through the well screen, moving outward and upward through the saturated zone. The sparging wells usually are connected by manifold piping to a compressor or blower, which supplies the air. Vertical or horizontal wells can be used to deliver the subsurface air/oxygen.

In order for IAS to be effective, contaminants must be relatively volatile and relatively insoluble. Contaminants to be sparged should have a Henry's Law Constant of  $1 \times 10^{-5}$  atmosphere-cubic meters per mole (atm-m<sup>3</sup>/mol) or greater and a water solubility of 20,000 mg/L or less.



In order to achieve adequate contaminant removal rates, injected air must flow freely throughout the saturated zone. An aquifer permeability of  $1 \times 10^{-4}$  cm/sec or greater is recommended for air sparging to be effective (USEPA, September 1992). Sparging is generally more effective in uniform, coarse-grained soils where air entry pressures (i.e., air injection pressure required to overcome the hydrostatic pressure head) are relatively low, and a more controlled air movement can be achieved. Fine-grained soils require higher air entry pressures that can create fractures (channeling) in the soil formation and limit the effectiveness of the process. Also, vertical air flow restrictions, such as clay lenses or zones of lower permeability above the air sparge point can cause air to move horizontally below the confining layer, potentially causing uncontrolled contaminant migration.

Due to the subsurface soil stratigraphy and the location of the contaminants of concern as described in Sections 2.4 and 2.5, it is recommended that the IAS system be installed horizontally within a trench. There are a few different options which would accomplish this and they are described in the following sections.

### **3.2 System Design Requirements**

The primary objective of the proposed IAS system is to assess the applicability and effectiveness of the technology in remediating contaminated groundwater. One measure of the effectiveness of the technology will be to determine if groundwater can be remediated to the established preliminary remediation goals, as presented in Table 2-1. In order to meet these proposed remediation goals Baker has considered system design parameters for the proposed IAS system, which are presented below. These design parameters will be included in the technical specifications.

#### **3.2.1 General System Description**

The estimated horizontal extent of contamination to be remediated for Site 35 is illustrated on Figure 2-9. It should be noted that the Phase I IRA represents the first phase, or portion of the final solution for OU No. 10. Therefore only a portion of the contaminated area will be addressed with this IAS system. The area of contamination, or plume, is based on data collected and evaluated by Baker and presented in the RI Report (Baker, 1995) and Draft SGI Report (Baker, 1996).

The proposed IAS system will include the following components:

- A horizontal air header located directly above the semi-confining unit.
- Multiple vertical drop pipes to distribute air to the horizontal air header.
- Header piping from the equipment (i.e. air compressors) to the vertical drop pipes.
- Air compressor(s) for supplying air to the IAS well, along with the associated receiving tank, piping, valves, instrumentation and control devices.

#### **3.2.2 Air Sparging Well Installation**

Two different options have been evaluated for installing the horizontal air sparging well. The first option consists of trenching to the desired depth and placing a horizontal air sparging header and associated vertical drop pipes within the trench and backfilling the trench with a more permeable

material than the surrounding soil. This option is the best way to insure that the horizontal air sparging system is effective as a sparge well. The other option would be to install the sparge well system utilizing horizontal drilling, and then trenching the area above the sparge well and backfilling with a more permeable material than the surrounding soil. This option assumes that the air will flow from the header upward through the native soil and into the backfilled trench.

Both options utilize trenching for the installation of the IAS system. Due to the depth of the trenches and the subsurface stratigraphy/groundwater table, careful consideration of the method of trenching to be utilized should be evaluated. Two different trenching methods have been evaluated for this site and are discussed in the following sections.

#### **3.2.2.1 Bio-Polymer Slurry Drainage Trench**

The Bio-Polymer Slurry Drainage Trench is constructed by excavating a narrow trench which is supported by the simultaneous pumping of a biodegradable bio-polymer slurry into the excavation. After the excavation of the trench, the horizontal header and multiple vertical drop pipes are installed through the slurry to the required depth. Following the installation of the structures, the trench is then backfilled with select filter materials. After the trench is completely installed and backfilled, the remaining bio-polymer slurry is converted back to a water/carbohydrate solution by the inclusion of a breaker agent or by the natural enzymes existing in the soil. Additional information concerning this technology is provided in the vendor literature in Appendix B.

One concern that would need to be considered with this method of installation is preventing the horizontal header screen from becoming clogged with the bio-polymer slurry.

#### **3.2.2.2 Sheet Piling**

The construction of a trench utilizing sheet piling consists of driving sheet piling to the desired depth on both sides of the proposed trench location, installing the necessary support system, and excavating the soils from between the sheet piling. After the excavation is completed the horizontal header and vertical drop pipes are installed prior to backfilling the trench with select filter materials. The use of sheet piling for this application would probably be more costly than a bio-polymer slurry trench, but this arrangement provides a work area that may make installation of the piping easier, and reduce the concern of clogging the horizontal header.

#### **3.2.2.3 One-Pass Trenching**

One-pass trenching is a construction method frequently used in utility installations. The method uses specialized equipment designed to cut a trench and allow for the installation of piping all in the same construction step. This method can save time and materials during the installation of a utility trench.

### **3.2.3 Air Sparging Header Design Considerations**

The following design considerations are recommended for the air sparging header:

- The horizontal header should be sized to minimize pressure drop along the pipes. 4 to 6 inch diameter pipe is recommended.

- The piping should be rated for compressed air service. Recommended piping materials include high density polyethylene (HDPE) or ABS piping. The screened portion of the horizontal air sparging pipe should be a pourous or corrugated HDPE pipe.
- The overall header length should be approximately 100 feet (for the Phase I system).
- The air shall be distributed to the horizontal header through multiple vertical drop pipes, which should be valved to provide control of the air supply.
- The air flow rate and gravel backfill needs to be controlled so that the groundwater does not migrate around the trench. This could happen if too much air is introduced into the trench, which essentially can make the trench less permeable than the surrounding native soil.

### **3.2.4 IAS Process Equipment Requirements**

The proposed IAS system for the Phase I IRA at Site 35 should be designed as a modular system that can be installed easily, and can be modified or relocated at the conclusion of the first phase of the project. A process flow schematic for the IAS system is presented in Figure 3-1. The contract specifications require that the Contractor submit detailed information on the specific equipment selected for the Phase I system.

### **3.3 Performance and Monitoring Requirements**

The overall goal for the IRA at Site 35 is to reduce the groundwater concentrations of the contaminants of concern to levels that are below the site remediation goals, as presented in Table 2-1. The objectives of Phase I of the IRA is to measure the reduction of contaminant concentrations obtained with the IAS system, and to use this information to determine if the IAS system can be expanded to provide a larger area of remediation.

An additional objective is to assess the impact of air emissions on human health and the environment and to verify that air emissions will not impact the planned highway project.

The specific performance requirements that the Phase I system will need to meet will depend on the actual size and arrangement of the IAS system. This arrangement will be proposed by the Contractor, using information from the IAS Treatability Study (Baker, 1996b), and the pre-interim remedial action field investigation (Baker, 1997: See Appendix C).

At a minimum, general performance requirements for the system will include the following items:

- An air compressor system capable of producing an adequate continuous supply of air to the IAS system.
- A header system capable of providing a uniform distribution of air.
- A system of monitoring points (i.e., monitoring wells, piezometers) that will allow for the collection of system operating data.

Monitoring requirements for the Phase I system will include the following:

- Groundwater contaminant data upgradient and downgradient of the IAS trench (An overall schedule for groundwater monitoring is provided in the specifications).
- Dissolved oxygen (DO) concentrations and air pressure data across the width of the IAS trench, and along the length of the IAS trench, to verify that the system is providing uniform air distribution.
- Dissolved Oxygen (DO) concentrations at monitoring points upgradient and downgradient of the system to provide data regarding the potential zone of influence of the IAS system.
- Groundwater levels from points upgradient and downgradient of the IAS trench.
- Ambient air monitoring at points surrounding the IAS trench, especially between the trench, the proposed highway right-of-way. Air samples will be analyzed for total VOCs. Consideration may be given to the implementation of continuous air monitoring by a portable Photo Ionization Detector (PID).
- Total VOCs in the off gas at the trench.

The specifications require the Contractor to develop a specific monitoring program, based on these overall monitoring requirements.

### **3.4 Special Considerations**

The following points should be considered by the Contractor when decisions are made regarding details of the design and construction of the IAS system.

#### *Existing Site Conditions*

The nature of the site presents some special considerations for construction and implementation of the proposed IAS system. Underground utilities are known to be present at the site, although their locations are not provided on any drawings. Therefore, all utility locations should be field verified prior to proceeding with drilling or excavation operations.

The Contractor will need to evaluate power requirements for the system and provide electric service to the location selected for the IAS equipment.

The subsurface stratigraphy identified during the previous investigations, as discussed in Section 2.4, have identified conditions that may not be favorable for an IAS with vertical air injection. Therefore, the installation of a horizontal header within a trench and backfilled with a more permeable material than the surrounding soil would provide a more efficient system to remediate the contamination at the site.

### *Air Sparging*

With the groundwater contamination being identified in the upper and lower portion of the surficial aquifer, it is imperative that the location of the air sparging header is installed properly. This location should be directly above the semi-confining unit or slightly into this unit.

The adjustment of the air flow into the trench must be monitored closely to prevent making the trench zone less permeable than the surrounding soils by introducing too much air into the trench. This would lead to a situation where the groundwater may move around the trench instead of through it.



#### 4.0 REFERENCES

- Baker. 1997. Feasibility Study, Operable Unit No. 10, Site 35 - Camp Geiger Area Fuel Farm. Marine Corps Base, Camp Lejeune, North Carolina.
- Baker. 1996a. Supplemental Groundwater Investigation (SGI) Report, Operable Unit No. 10, Site 35 - Camp Geiger Area Fuel Farm. Marine Corps Base, Camp Lejeune, North Carolina.
- Baker. 1996b. Treatability Study Work Plan, Pilot-Scale Evaluation of In-Situ Air Sparging. Marine Corps Base, Camp Lejeune, North Carolina.
- Baker. 1995a. Remedial Investigation Report, Operable Unit No. 10, Site 35, Camp Geiger Fuel Farm. Marine Corps Base, Camp Lejeune, North Carolina.
- Baker. 1995b. Record of Decision (ROD) for Surficial Groundwater for a Portion of Operable Unit No. 10. Camp Geiger Area Fuel Farm. Marine Corps Base Camp Lejeune, North Carolina.
- Baker. 1995c. Interim Feasibility Study for Shallow Groundwater in the Vicinity of the Former Fuel Farm. Marine Corps Base, Camp Lejeune, North Carolina.
- Baker. 1994. Baker Environmental Inc. Interim Remedial Action, Remedial Investigation/Feasibility Study, Operable Unit No. 10, Site 35 - Camp Geiger Fuel Farm. Marine Corps Base, Camp Lejeune, North Carolina.
- ESE, 1990. Final Site Summary Report, MCB Camp Lejeune. ESE Project No. 49-02036, September 1990.
- Groundwater Technology, Inc., March 10, 1992. Air Sparging Guidance Document (Internal Memorandum)
- Law. 1993. Addendum to Report of Underground Fuel Investigation and Comprehensive site Assessment. Camp Geiger Fuel Farm, Marine Corps Base, Camp Lejeune, North Carolina.
- Law. 1992. Final Report, Underground Fuel Investigation and Comprehensive site Assessment. Camp Geiger Fuel Farm. Marine Corps Base, Camp Lejeune North Carolina.
- Marley, Michael C. and Droste, Edward X. Summer 1995 Remediation Journal, Successfully Applying Sparging Technologies
- Naval Facilities Engineering Command, Atlantic Division. April 1993. Guide for Architect Engineer Firms Performing Services for the Atlantic Division Naval Facilities Engineering Command.
- Naval Energy and Environmental Support Activity (NEESA), and Naval Facilities Engineering Command Contractor's Office, June 1992. NEESA 20.2-062. Remedial Action Contracts Delivery Order Requirements Package Guide, Parts 1 and 2.
- NUS. 1990. Draft Field Investigation/Focused Feasibility Study Camp Geiger Fuel Spill Site, Marine Corps Base, Camp Lejeune, North Carolina.

Pankow, James F., Johnson, Richard L., and Cherry, John A. July 1993, GROUNDWATER, Air Sparging in Gate Wells in Cutoff Walls and Trenches for Control of Plumes of Volatile Organic Compounds (VOCs).

U.S. EPA, September 1992. A Technology Assessment of Soil Vapor Extraction and Air Sparging.

Water and Air Research, Inc. 1983. Initial Assessment Study of Marine Corps Base Camp Lejeune, North Carolina. Prepared for Naval Energy and Environmental Support Activity.

**FIGURES**

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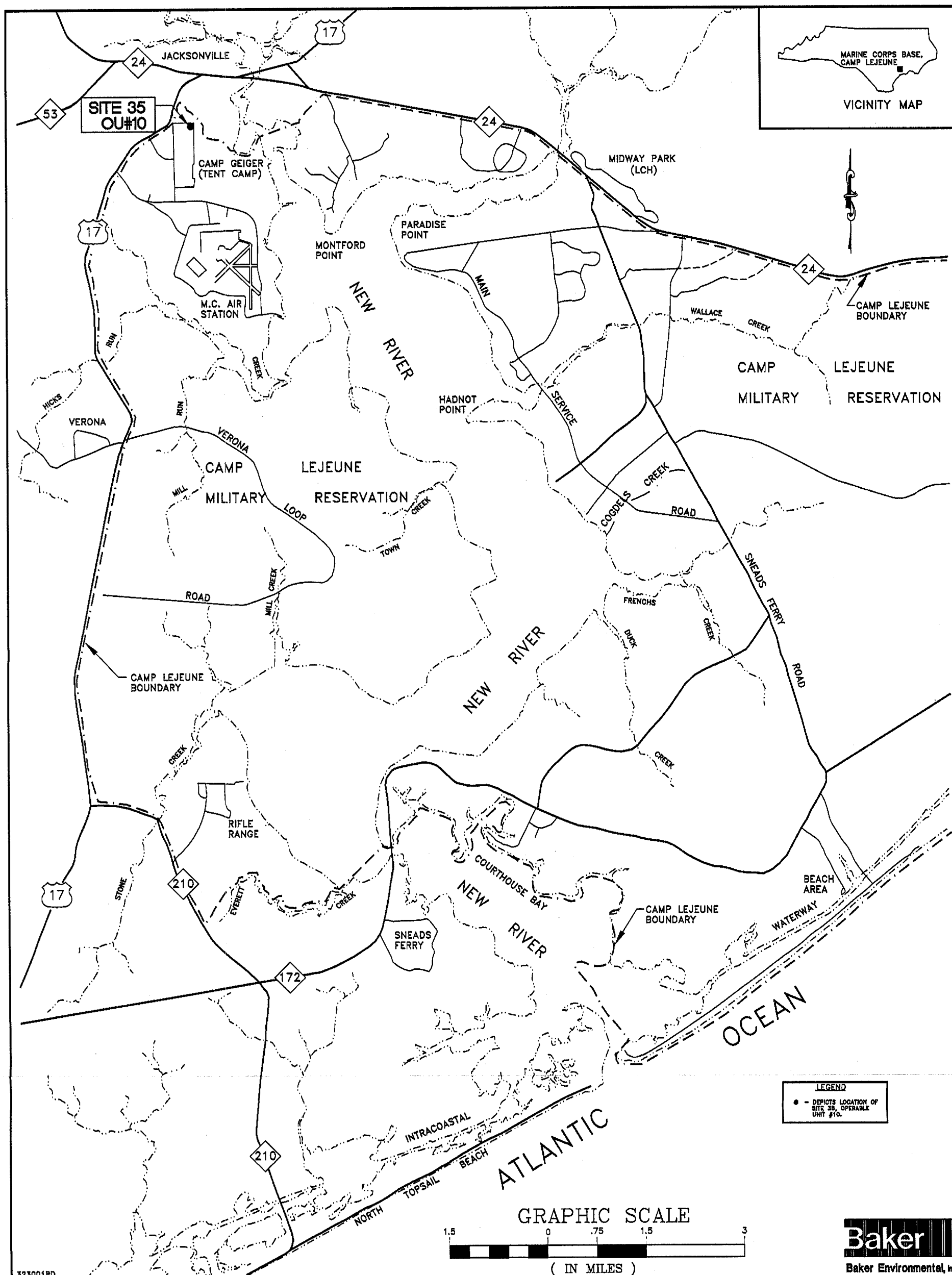


FIGURE 2-1  
CAMP LEJEUNE AND SITE 35 LOCATION MAP  
SITE 35, CAMP GEIGER AREA FUEL FARM  
INTERIM REMEDIAL ACTION, BASIS OF DESIGN  
CONTRACT TASK ORDER - 0323  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

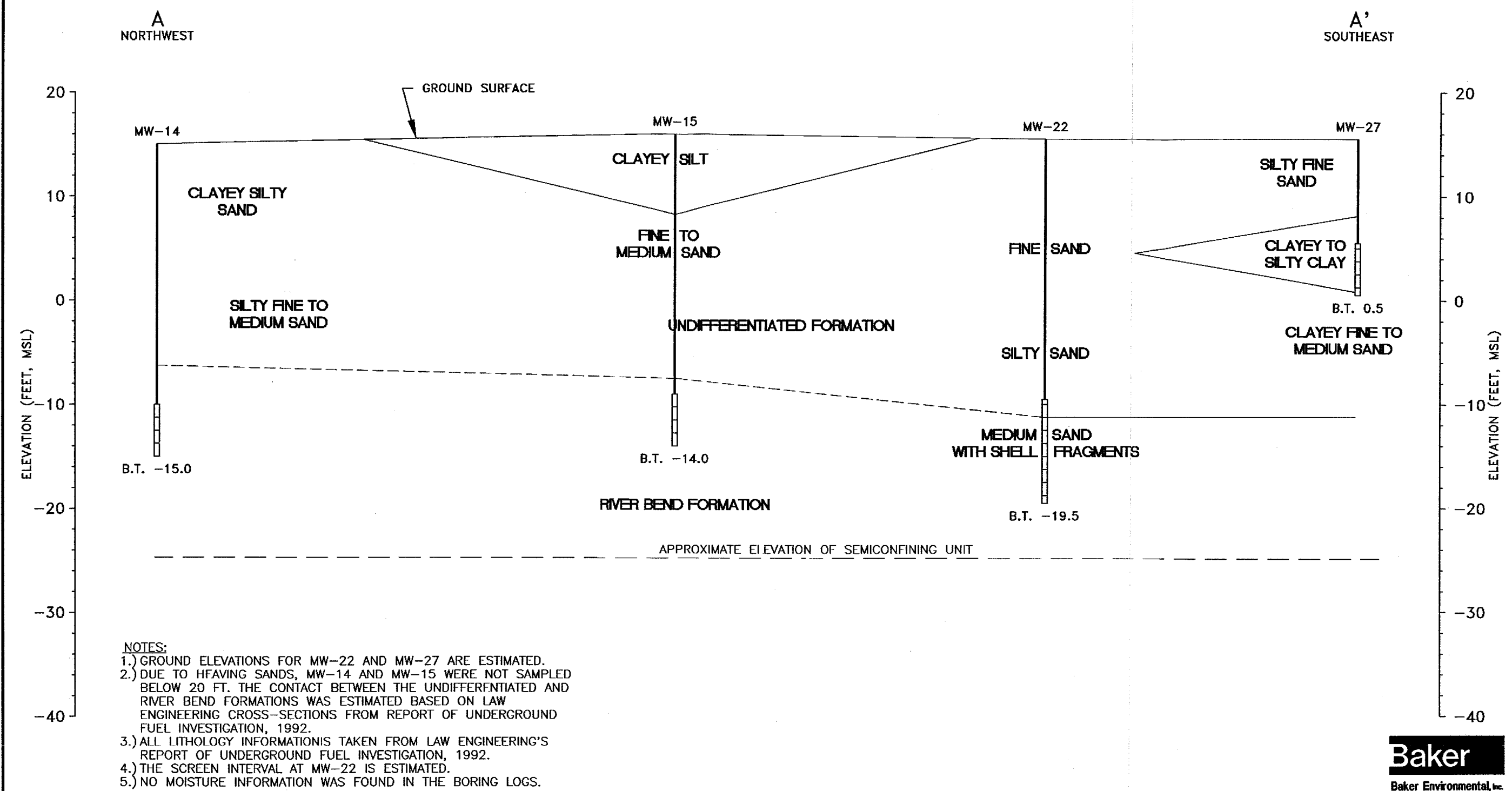
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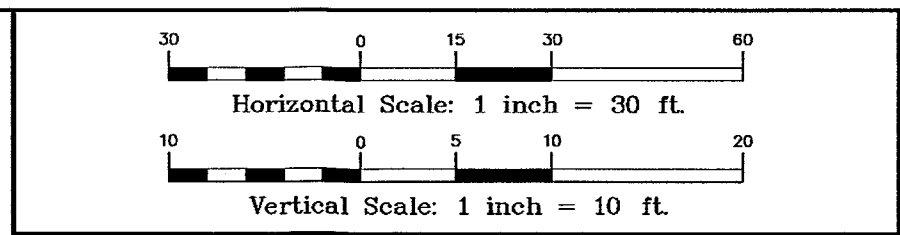
**Baker**  
Baker Environmental, Inc.

**LEGEND**

▮ WELL SCREEN INTERVAL

— ESTIMATED

--- PROJECTED



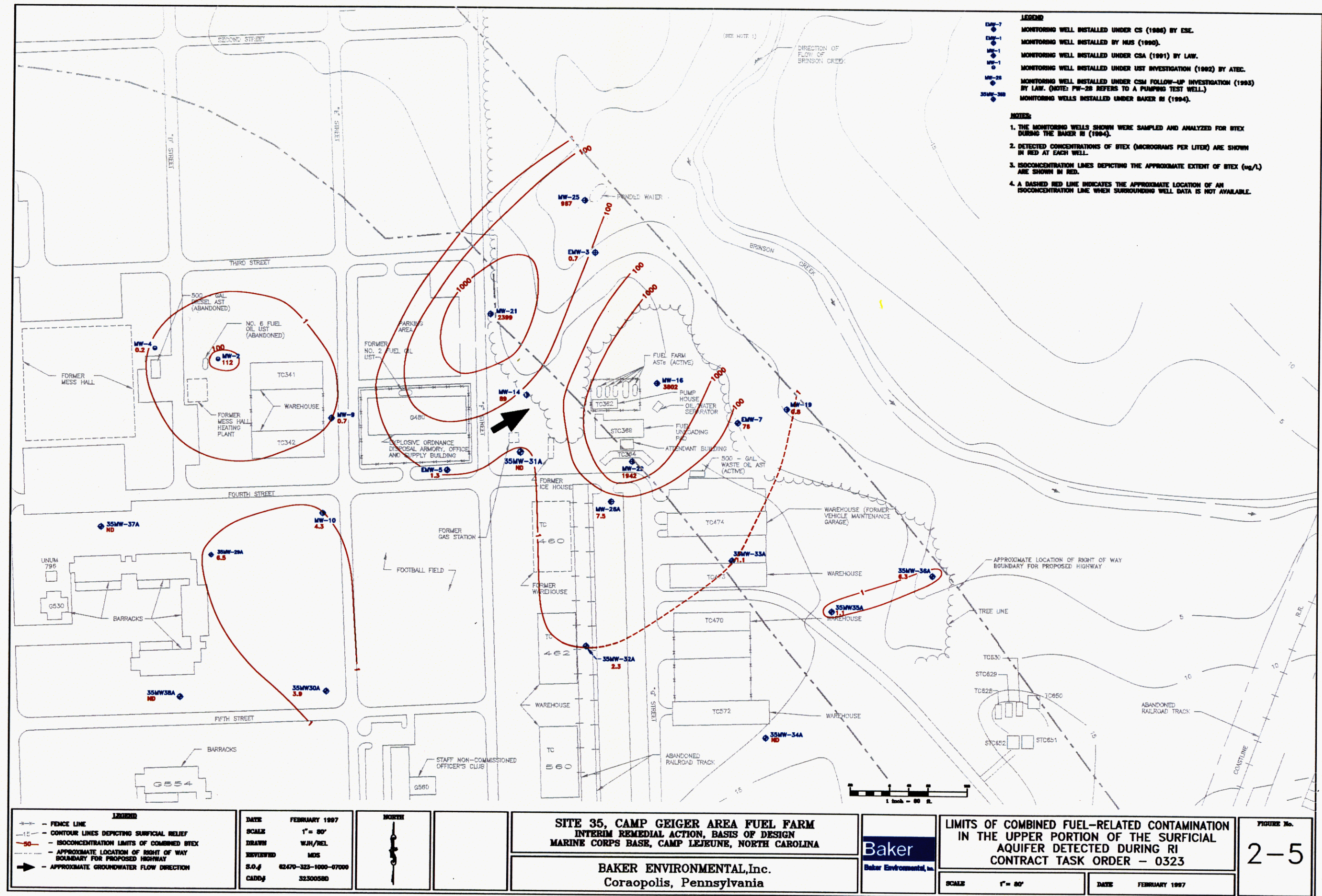
THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

**FIGURE 2-4**  
**GEOLOGIC CROSS-SECTION A-A'**  
**SITE 35, CAMP GEIGER AREA FUEL FARM**  
**INTERIM REMEDIAL ACTION, BASIS OF DESIGN**  
**CTO - 0323**

MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

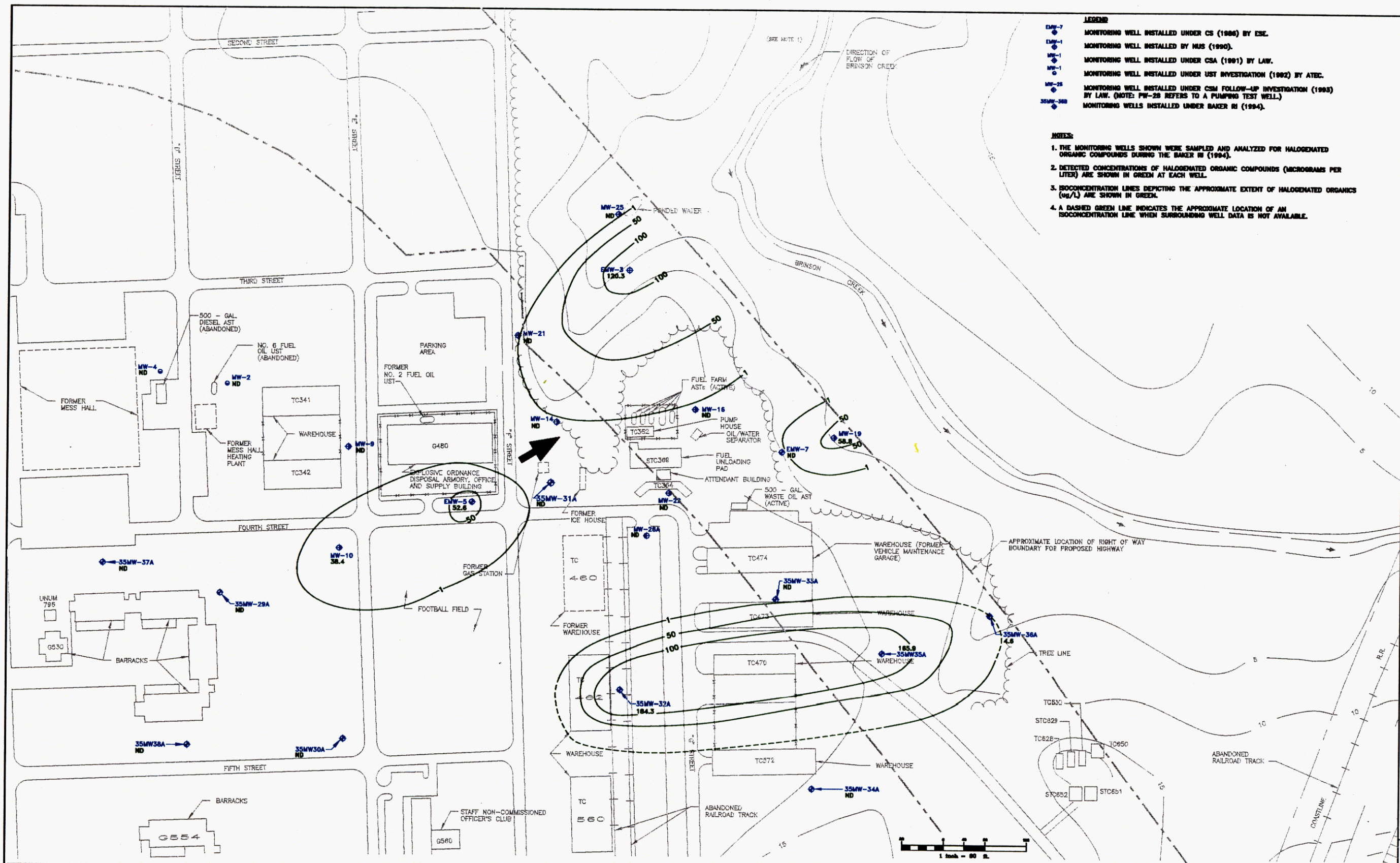
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- LEGEND**
- MW-1 MONITORING WELL INSTALLED UNDER CS (1986) BY ESE.
  - MW-2 MONITORING WELL INSTALLED BY MUS (1990).
  - MW-3 MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.
  - MW-4 MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.
  - MW-5 MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)
  - MW-6 MONITORING WELLS INSTALLED UNDER BAKER RI (1994).

- NOTES**
1. THE MONITORING WELLS SHOWN WERE SAMPLED AND ANALYZED FOR HALOGENATED ORGANIC COMPOUNDS DURING THE BAKER RI (1994).
  2. DETECTED CONCENTRATIONS OF HALOGENATED ORGANIC COMPOUNDS (MICROGRAMS PER LITER) ARE SHOWN IN GREEN AT EACH WELL.
  3. ISOCONCENTRATION LINES DEPICTING THE APPROXIMATE EXTENT OF HALOGENATED ORGANICS (UG/L) ARE SHOWN IN GREEN.
  4. A DASHED GREEN LINE INDICATES THE APPROXIMATE LOCATION OF AN ISOCONCENTRATION LINE WHEN SURROUNDING WELL DATA IS NOT AVAILABLE.

- LEGEND**
- FENCE LINE
  - 15- CONTOUR LINES DEPICTING SURFICIAL RELIEF
  - 50- ISOCONCENTRATION LIMITS OF COMBINED HALOGENATED ORGANICS.
  - - - - - APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY
  - ➔ APPROXIMATE GROUNDWATER FLOW DIRECTION

DATE FEBRUARY 1997  
 SCALE 1" = 50'  
 DRAWN WJH/REL  
 REVIEWED MDS  
 S.O.# 62470-323-1000-07000  
 CADD# 32300680

NOTES

**SITE 35, CAMP GEIGER AREA FUEL FARM FS**  
 INTERIM REMEDIAL ACTION, BASIS OF DESIGN  
 MARINE CORPS BASE, CAMP LEJUNE, NORTH CAROLINA

**BAKER ENVIRONMENTAL, Inc.**  
 Coraopolis, Pennsylvania

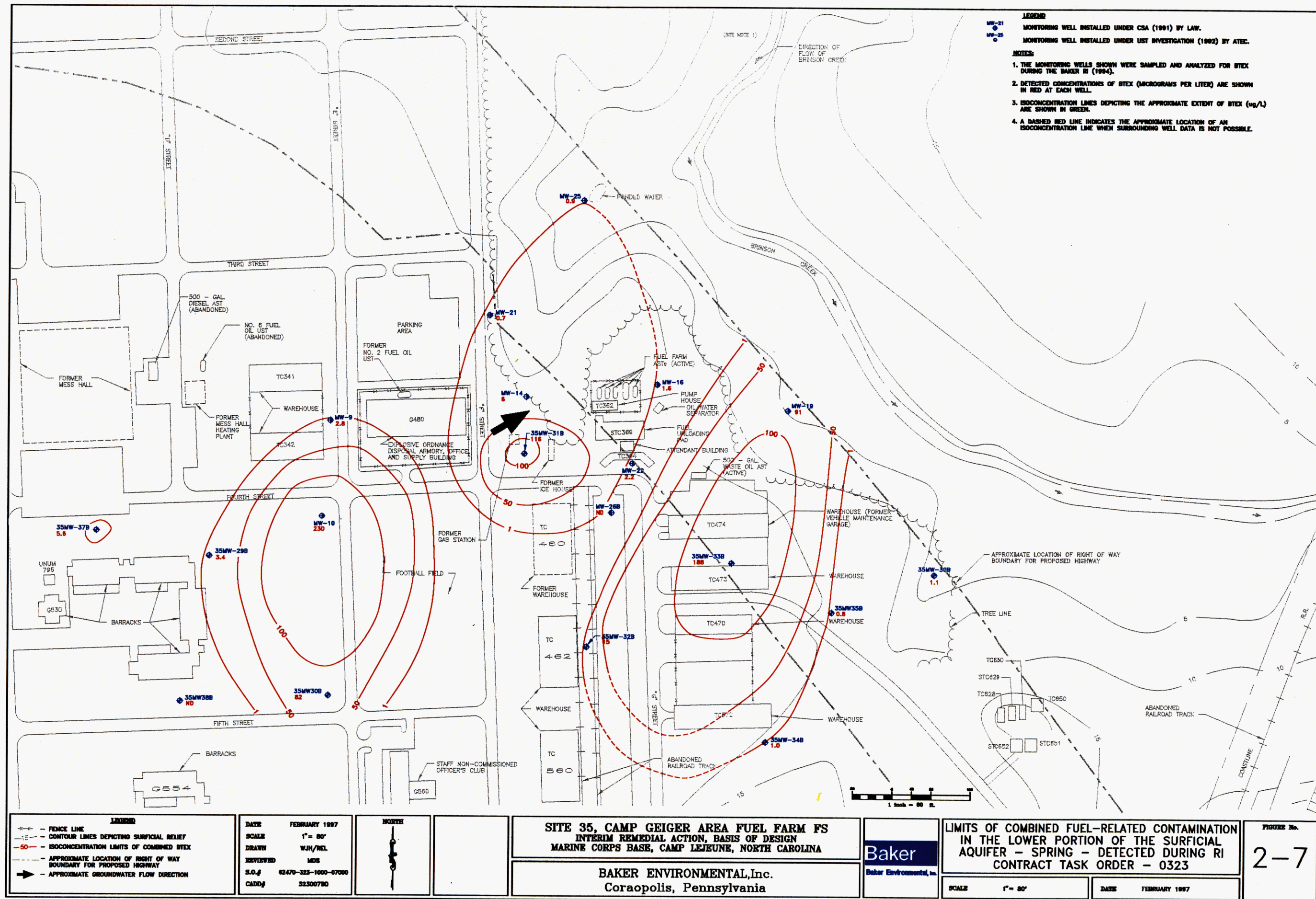
**Baker**  
 Baker Environmental, Inc.

**LIMITS OF COMBINED SOLVENT-RELATED CONTAMINATION IN THE UPPER PORTION OF THE SURFICIAL AQUIFER DETECTED DURING RI CONTRACT TASK ORDER - 0323**

SCALE 1" = 50' DATE FEBRUARY 1997

FIGURE No.  
**2-6**











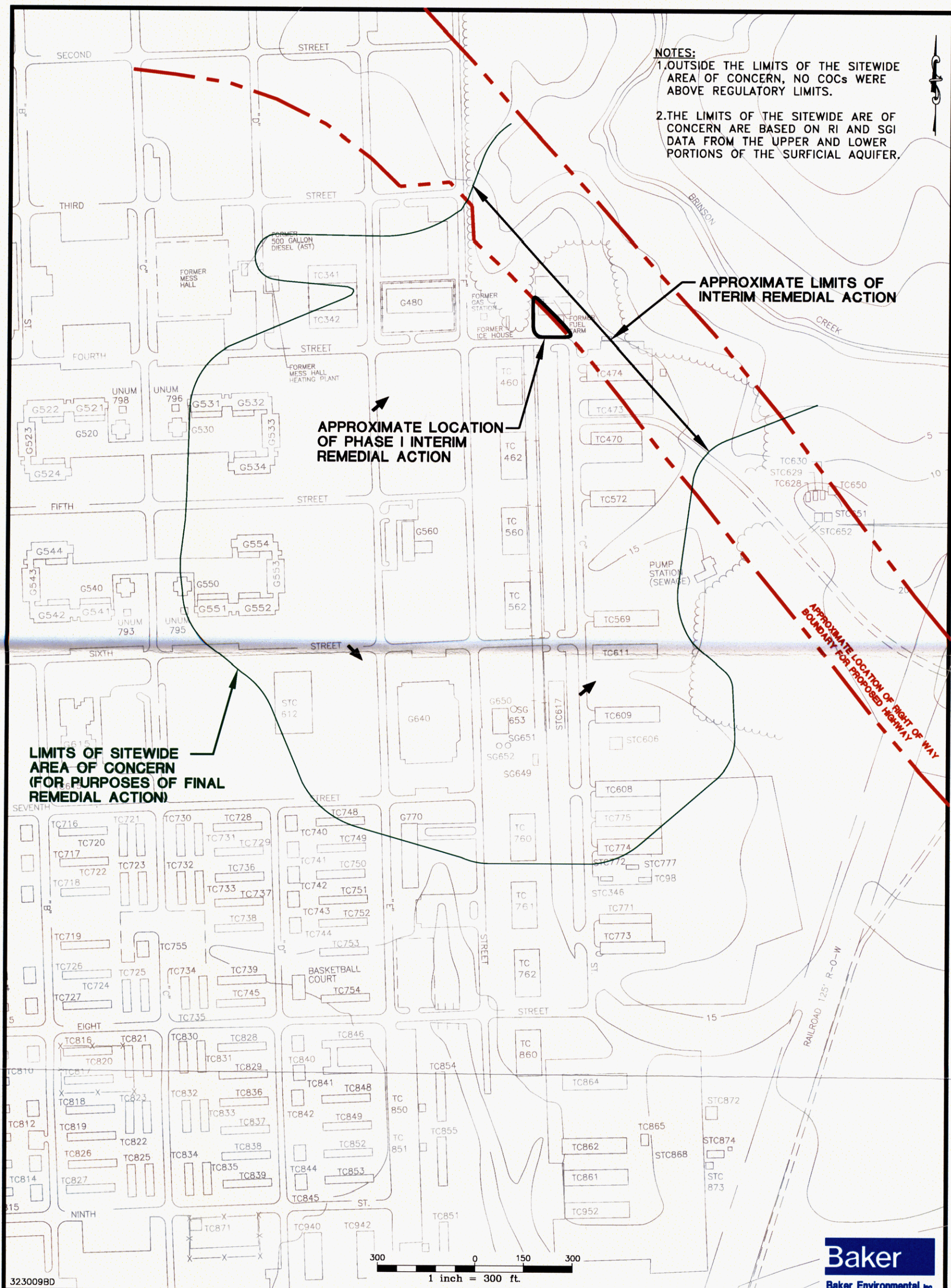
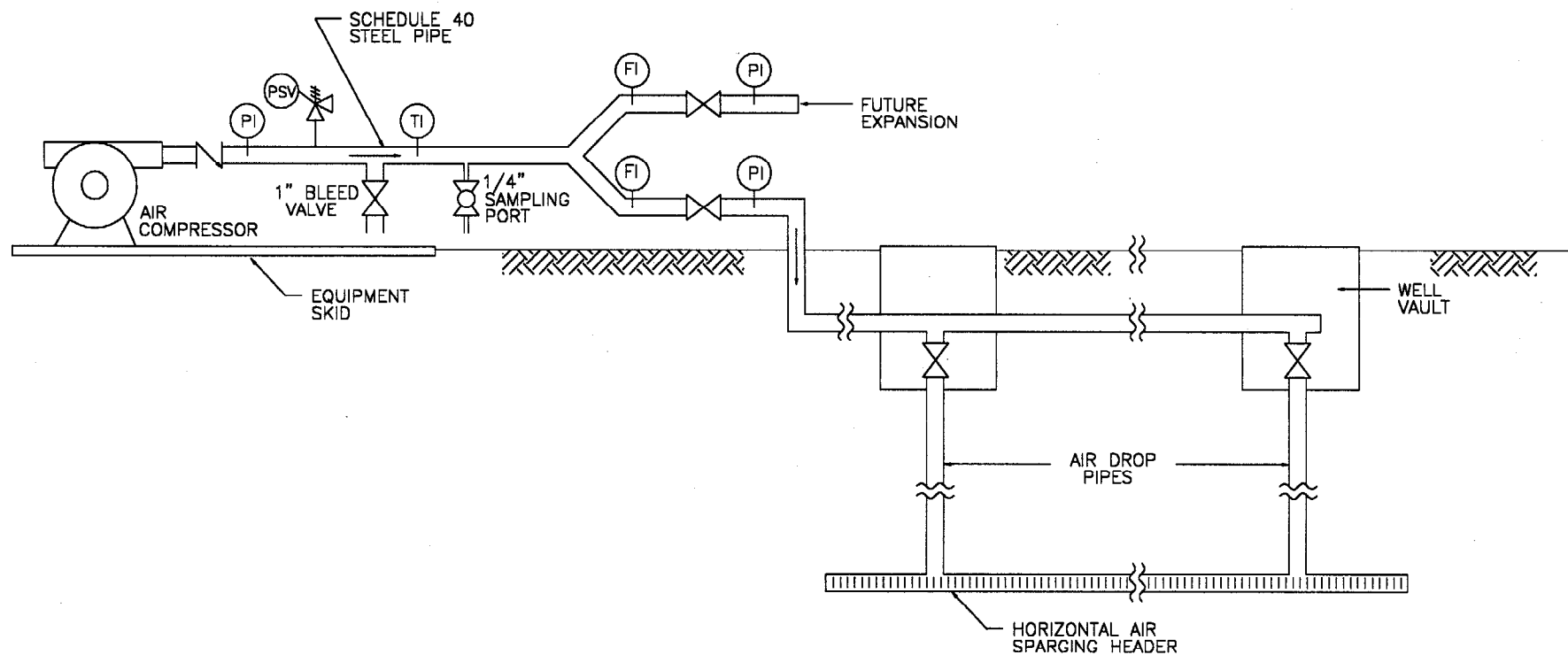


FIGURE 2-9  
SITE-WIDE AREA OF CONCERN  
SITE 35, CAMP GEIGER AREA FUEL FARM FS  
INTERIM REMEDIAL ACTION, BASIS OF DESIGN  
CONTRACT TASK ORDER - 0323  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA



**Baker**

Baker Environmental, Inc.

**LEGEND**

	GATE VALVE	FI - FLOW INDICATOR
	BALL VALVE	PI - PRESSURE INDICATOR
	CHECK VALVE	TI - TEMPERATURE INDICATOR
	PRESSURE SAFETY VALVE (PSV)	

**FIGURE 3-1**  
**HORIZONTAL AIR SPARGING**  
**PROCESS FLOW SCHEMATIC**  
**OPERABLE UNIT NO. 10 (SITE 35)**

MARINE CORPS BASE, CAMP LEJEUNE  
 NORTH CAROLINA

**INTERIM REMEDIAL ACTION**  
**COST ESTIMATE FOR IN SITU AIR SPARGING TRENCH**  
**CTO - 0323**  
**SITE 35, CAMP GEIGER AREA FUEL FARM**  
**MCB CAMP LEJEUNE, NORTH CAROLINA**

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
<b>DIRECT CAPITAL COSTS:</b>							
<b>GENERAL COSTS FOR THE TREATMENT SYSTEM</b>							
Preconstruction Submittals	LS	1	\$8,840.00	\$8,840		Work Plan, E&SNPDES Plans, H&S Plans, QC Plans, Shop Drawings	Engineering Estimate, See Table 1
Mobilization/Demobilization	LS	1	\$23,154.00	\$23,154		Includes OHM mob only. Drillers and trenching subs are in unit costs	Engineering Estimate, See Table 1
Decontamination Pad/ Laydown Area	LS	1	\$2,200.00	\$2,200		Decon pad for OHM vehicles	Engineering Estimate, See Table 1
Contract Administration	LS	1	\$20,000.00	\$20,000		Invoicing, shop drawings, etc. Previous FS estimates	Engineering Estimate
Post-Construction Submittals	LS	1	\$3,736.00	\$3,736		Includes misc. progress reports	Engineering Estimate, see Table 1
<b>TOTAL GENERAL COSTS FOR THE TREATMENT SYSTEM</b>					<b>\$55,930</b>		
<b>SITE WORK</b>							
<b>Construct Soil Storage Area For Contaminated Soil</b>							
Mulch Hay Bale	EA	170	\$3.57	\$607		Assume temporary holding area for soil is 100' x 100'	
60 mil Polymeric Liner	SF	13225	\$1.38	\$18,251		400' x 100' divider for clean and contaminated soil. Bales 36" long	Means Echos 1996, 17 03 9904 Assemblies
Waste Pile Cover	SY	13225	\$1.83	\$24,202		115' x 115', to place soil on	Means Echos 1996, 33 08 0544 Assemblies
						120' x 120', to cover soil pile	Means Echos 1996, 33 08 0590 Assemblies
<b>Move Contaminated Soil To Storage Area</b>							
Set Poly Liner Per Load in Dump Truck	Each	50	\$40.00	\$2,000		Move soil from Site 35 to proposed biceff location. Assume 50 loads	
Load and Transport Soil	CY	445	\$6.00	\$2,670		Liners needed due to semi liquid nature of slurry	Previous cost estimate.
						Assume 100' (length) x 3' (width) x 40' (depth) / 27 = 444 cubic yards	Means 1996, Echos
<b>Testing On Site For Waste Categorizing And IDW</b>							
Mobile On-Site Lab Mob/Demob	EA	1	\$700.00	\$700		Include lab personnel	Baker 1996 Basic Ordering Agreement
Lab operation	DAY	3	\$2,000.00	\$6,000		Assume 3 days of sampling.	Baker 1996 Basic Ordering Agreement
OHM Sampling Personnel	HR	60	\$14.00	\$840		3 sampling technicians 10 hrs/day for 3 days	Previous Cost Estimate
Confirmatory Sampling (fixed base lab)	EA	25	\$150.00	\$3,750		Costs includes analysis and validation for VOC for matrix, and blanks	Baker 1996 Basic Ordering Agreement
IDW-IDW Analysis	LS	1	\$800.00	\$800		RCRA and full suite of CLP data for decon fluids	Baker 1996 Basic Ordering Agreement
IDW-Vac poly and transport decon fluids to plant.	EA	1	\$1,500.00	\$1,500		Vac out poly tank and transport to makside	Previous Baker job.
<b>Utility relocation (storm drain)</b>							
Excavate to 6' bgs	CY	133	\$71	\$94		Assume 150 LF of storm drain to be relocated	
Backfill with excavated material	CY	133	\$89	\$118		150' x 6' x 4' / 27 = 133 CY	Means Echos 1996 - 17 03 0258 Assemblies
Compacting in 6" Lifts	CY	133	\$1.19	\$158			Means Echos 1996 - 17 03 0401 Units
15" RCP, install and materials	LF	150	\$11.52	\$1,728			
Headwall	EA	1	\$469.00	\$469		Means Echos 1996, 19 03 0166 Assemblies Book	Means Echos 1996 - 19 03 0166 Assemblies
IAS System Monitoring Wells	LS	1	\$36,811.32	\$36,811		Install 8 wells, to monitor efficiency of IAS systems abandon existing	Means Echos 1996 - 19 03 0505 Assemblies
Grading And Seeding	SY	416	\$4.38	\$1,822		Triangular area .5 x 150' x 150' = 416 SY	Engineering Estimates - Table 2
Topsoil	CY	18	\$21.00	\$378		Soil dumped at the site. 100' x 50' x .5' / 27 = 18 CY	Eng. Estimate; Previous Projects
<b>TOTAL SITE WORK</b>					<b>\$102,899</b>		



**INTERIM REMEDIAL ACTION**  
**COST ESTIMATE FOR IN SITU AIR SPARGING TRENCH**  
**CTO - 0323**  
**SITE 35, CAMP GEIGER AREA FUEL FARM**  
**MCB CAMP LEJEUNE, NORTH CAROLINA**

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
<b>IN SITU AIR SPARGE (IAS) INJECTION TRENCH</b>							
IAS installation via biopolymer trenching	SF	4000	\$10.00	\$40,000		100' x 40' trench	Vendor
Gravel	CY	445	\$20.45	\$9,100		Gravel to serve as packing in trench. 100' x 40' x 3'	Means Echos 1996 1703 0418 Units Book
2" HDPE Riser and Header	LF	150	\$5.00	\$750		Materials and installation ,riser and header pipes	Vendor
<b>TOTAL</b>					<b>\$49,850</b>		
<b>IN SITU AIR SPARGING EQUIPMENT AND INSTALLATION</b>							
Blower , 98 SCFM, 3.2 HP, 5PSI	EA	1	\$4,528.71	\$4,528		Cost of blower installation is included in the cost	Means Echos 1996 33 13 9001 Assemblies Book
Trailer mounting	EA	1	\$772.98	\$773			Means Echos 1996 33 13 2308 Assemblies Book
Check Valve	EA	3	\$200.00	\$600			Means Echos 1996 33 27 0402 Assemblies Book
Pressure Gauge	EA	2	\$138.73	\$273			Means Echos 1996 33 27 0209 Assemblies Book
Misc. Fittings	LS	1	\$5,638.40	\$5,638		20% of IAS total equipment cost	Eng. Estimate; Previous Projects
Equipment Installation	EA	1	\$4,228.80	\$4,228		Installation of fittings, gauges, and valves. 75% of cost for these items	Eng. Estimate; Previous Projects
Start-up	HR	420	\$14.00	\$5,880		2 techs per shifts. Days 1-5, 2 shifts. Days 6-30, 1 shift. 8 hr shift.	Eng. Estimate
Samples	EA	270	\$150.00	\$40,500		Days 1-5 every 12 hrs. Days 6-30 every 24 hrs. 8 wells	Eng. Estimate; Previous Projects
Shipping	EA	30	\$180.00	\$5,400		1 cooler per day.	Eng. Estimate
<b>TOTAL IN SITU AIR SPARGING EQUIPMENT AND INSTALLATION</b>					<b>\$87,822</b>		
<b>TOTAL DIRECT CAPITAL COSTS</b>					<b>\$276,501</b>		
<b>INDIRECT CAPITAL COSTS</b>							
Engineering and Design	LS	1	\$8,464.00	\$8,464		Table 3	Engineering Estimate
Construction Administration/ Distributive Costs	LS	1	\$25,388.00	\$25,388		Table 3	Engineering Estimate
Contingency Allowance	LS	1	\$41,475.18	\$41,475		15% of Total Direct Capital Costs	Engineering Estimate
Set-Up Costs	LS	1	\$7,564.00	\$7,564		Table 3	Engineering Estimate
<b>TOTAL INDIRECT CAPITAL COSTS</b>					<b>\$80,891</b>		

**INTERIM REMEDIAL ACTION  
COST ESTIMATE FOR IN SITU AIR SPARGING TRENCH  
CTO - 0323  
SITE 35, CAMP GEIGER AREA FUEL FARM  
MCB CAMP LEJEUNE, NORTH CAROLINA**

COST COMPONENT	UNIT	QUANTITY	UNIT COST	SUBTOTAL COST	TOTAL COST	BASIS OR COMMENTS	SOURCE
<b>O&amp;M COSTS:</b>							
TREATMENT SYSTEM - O&M							
Labor Sampling	Hours	280	\$14.00	\$3,920		Assume monthly event for 6 months of operation 8 wells, 2 techs, 1 day	Engineering Estimate. See Table 4.
Laboratory Analysis:							
Groundwater Samples	Sample	140	\$150	\$21,000		Wk 1 = 30 samples, wks 2-8 = 70 samples, & wks 9-20 = 40 samples	Engineering Estimate. See Table 4.
Equipment, Supplies & Shipping	LS	1	\$3,000	\$3,000		Ice, DI water, expendables, pump, IDW related charges, & shipping.	Engineering Estimate
Reporting	LS	1	\$3,000	\$3,000		Laboratory reports, administration, produced at the end of 6 months	Engineering Estimate
Labor for Plant O&M	Hours	208	\$14	\$2,912		Assumed 8 hrs/week for 26 weeks/year at \$14/hr	Engineering Estimate
Administration and Records	Hours	50	\$14	\$700		Approx 2 hrs per week for 26 weeks = 50 hrs for 6 months. Rate \$14/hr	Engineering Estimate
Electricity	KWH	4320	\$.07	\$302		24 hours/day for 180 days (6 months) operation	Means Echos 1996
<b>TOTAL ESTIMATED O&amp;M COSTS (6 MONTH OPERATING PERIOD)</b>					<b>\$34,834</b>		
<b>TOTAL DIRECT AND INDIRECT COSTS</b>					<b>\$357,392</b>		
<b>TOTAL ANNUAL O &amp; M COSTS</b>					<b>\$34,834</b>		



**TABLE 1**  
**COST ESTIMATE, DIRECT GENERAL COSTS FOR THE INSTALLATION OF AN**  
**IN SITU AIR SPARGING TRENCH**

Cost Items	Unit Costs	Units	Number Units	Costs	Source
<b>PRECONSTRUCTION SUBMITTALS</b>					
Erosion Control Plan	\$22.00	HR	20	\$440.00	CTO 338 RAC
Environmental Protection Plan	\$22.00	HR	40	\$880.00	CTO 274 RAC
Site Health and Safety Plan	\$22.00	HR	40	\$880.00	CTO 274 RAC
Work Plan	\$22.00	HR	60	\$1,320.00	CTO 274 RAC
Construction QA/QC Plan	\$22.00	HR	40	\$880.00	CTO 338 RAC
Permits	\$22.00	HR	20	\$440.00	CTO 274 RAC
Misc Site Visit	\$2,000.00	EA	1	\$2,000.00	Eng. Estimate
<b>TOTAL PRECONSTRUCTION SUBMITTALS</b>				<b>\$6,840.00</b>	
<b>MOB/DEMOB COSTS</b>					
<b>Mob</b>					
Mob/Demob Office Trailer	\$500.00	EA	1	\$500.00	CTO 274 RAC
Mob/Demob Equip. Trailer	\$500.00	EA	1	\$500.00	Eng. Estimate
Mob Front loader	\$500.00	EA	1	\$500.00	Eng. Estimate
Mob tractor (landscaping)	\$500.00	EA	1	\$500.00	Eng. Estimate
Mob Dump Trucks	\$500.00	EA	3	\$1,500.00	Eng. Estimate
Mob Tractor Trailer	\$500.00	EA	1	\$500.00	Eng. Estimate
Generator	\$50.00	EA	1	\$50.00	CTO 338 RAC
Pressure Wash	\$50.00	EA	1	\$50.00	CTO 338 RAC
Mob Management Personnel	\$2,000.00	EA	3	\$6,000.00	CTO 274 RAC
<b>Demob</b>					
Poly Tank Rental	\$150.00	MO	2	\$300.00	Previous project
Decon of equipment	\$200.00	EA	4	\$800.00	
Demob of Heavy Equipment	\$3,000.00	LS	1	\$3,000.00	Same as mob
Demob Personnel	\$6,000.00	LS	1	\$6,000.00	Same as mob
Trash pump	\$60.00	DAY	5	\$300.00	
General Site Clean-up	\$500.00	LS	1	\$500.00	
Security Fence	\$3.59	FT	600	\$2,154.00	Eng Estimate
<b>TOTAL MOD AND DEMOB COSTS</b>				<b>\$23,154.00</b>	

**TABLE 1 (Continued)**  
**COST ESTIMATE, DIRECT GENERAL COSTS FOR THE INSTALLATION OF AN**  
**IN SITU AIR SPARGING TRENCH**

Cost Items	Unit Costs	Units	Number Units	Costs	Source
<b>DECON PAD</b>					
Pad construction	\$1,500.00	EA	1	\$1,500.00	Previous Baker job.
Pad demob	\$700.00	EA	1	\$700.00	Eng. Estimate
<b>TOTAL DECON PAD</b>				<b>\$2,200.00</b>	
<b>POST CONSTRUCTION SUBMITTALS</b>					
Punch List	\$22.00	HR	6	\$132.00	Eng. Estimate
Post Const. Documentation (Disposal Certification)	\$132.00	LS	1	\$132.00	RAC Design CTO 338
<b>Documentation Report</b> ( Personnel, Final Engineering Report)					
Introduction - Tech.	\$22.00	HRS	2	\$44.00	RAC Design CTO 338
Summary of Action - Tech	\$22.00	HRS	16	\$352.00	RAC Design CTO 338
Final H & S Report	\$22.00	HRS	16	\$352.00	RAC Design CTO 338
Summary of Record Docs - Tech	\$22.00	HRS	16	\$352.00	RAC Design CTO 338
Contract Mods. - Tech	\$22.00	HRS	16	\$352.00	RAC Design CTO 338
Final Documents - Tech	\$22.00	HRS	8	\$176.00	RAC Design CTO 338
Summary of Testing - Tech	\$22.00	HRS	8	\$176.00	RAC Design CTO 338
Off-Site Disposal of Materials - Tech	\$22.00	HRS	8	\$176.00	RAC Design CTO 338
QA/QC Summary Report - Tech	\$22.00	HRS	8	\$176.00	RAC Design CTO 338
Technical Supervision	\$34.00	HRS	16	\$544.00	RAC Design CTO 338
Clerical	\$12.00	HRS	20	\$240.00	RAC Design CTO 338
Reproduction	\$10.00	HRS	6	\$60.00	RAC Design CTO 338
<b>As Built Drawings</b>					
Site Supervisor	\$22.00	HRS	16	\$352.00	RAC Design CTO 338
Drafting Tech	\$15.00	HRS	8	\$120.00	RAC Design CTO 338
<b>TOTAL POST CONSTRUCTION SUBMITTALS</b>				<b>\$3,736.00</b>	

**TABLE 2**  
**COST ESTIMATE FOR THE INSTALLTION OF AS**  
**SYSTEM MONITORING WELLS**

Survey permanent well locations

Install 8 permanent wells. Install 2 wells per day.

Assume shallow = 15' bgs and intermediate = 43' bgs.

<b>DRILLING COSTS</b>				
8 permanent wells up and downgradient of IAS trench.				
<b>COST ITEMS</b>	<b>QUANTITY</b>	<b>UNIT</b>	<b>COST PER UNIT</b>	<b>TOTAL COST</b>
Mob rig & backhoe	2	ea.	\$500.00	\$1,000.00
Backhoe	1	week	\$3,000.00	\$3,000.00
6.25" augering	232	ft	\$15.00	\$3,480.00
Split Spoon Sampling (perm.)	24	ea	\$15.00	\$360.00
Riser (2" ND)	172	ft.	\$1.25	\$215.00
Screen (2" ND, 10' long)	4	ea.	\$20.00	\$80.00
Screen (2" ND, 5' long)	4	ea.	\$12.00	\$48.00
2" Well Installation	232	ft.	\$16.50	\$3,828.00
Decontamination pad	1	ea.	\$200.00	\$200.00
Standby/IDW Mgt.	8	hr.	\$150.00	\$1,200.00
IDW contain. solid	1	LS	\$1,260.00	\$1,260.00
IDW contain. liquid	1	LS	\$3,250.00	\$3,250.00
Protective Cover	8	ea	\$400.00	\$3,200.00
Well development	24	hr	\$65.00	\$1,560.00
Per diem (3 man crew)	5	day	\$95.00	\$475.00
<b>SUBTOTAL</b>				<b>\$23,156.00</b>

<b>ODCs</b>				
<b>COST ITEMS</b>	<b>QUANTITY</b>	<b>UNIT</b>	<b>COST PER UNIT</b>	<b>TOTAL COST</b>
HNu	5	day	\$11.04	\$55.20
pH meter	5	day	\$6.35	\$31.75
Conductivity meter	5	day	\$3.86	\$19.30
Turbidity meter	5	day	\$9.67	\$48.35
2 channel hermit	5	day	\$75.00	\$375.00
Van rental	5	day	\$50.00	\$250.00
Lodging	10	day	\$47.00	\$470.00
Airfare	2	ea.	\$721.00	\$1,442.00
Parking	10	day	\$5.50	\$55.00
Meals	10	day	\$26.00	\$260.00
Sample shipping	3	ea.	\$80.00	\$240.00
Log book	2	ea.	\$6.57	\$13.14
Water level	5	day	\$2.52	\$12.60
H&S expendibles	5	day	\$30.00	\$150.00
Sampling expendibles	1	event	\$145.00	\$145.00
Decon. expendibles	1	event	\$221.00	\$221.00
<b>SUBTOTAL</b>				<b>\$3,788.34</b>

**TABLE 2**  
**COST ESTIMATE FOR THE INSTALLTION OF AS**  
**SYSTEM MONITORING WELLS**

<u><b>SURVEYING</b></u>		Surveying 2,000 feet ROW and wells.		
TASKS	QUANTITY	UNIT	LABOR RATE	TOTAL COST
Survey	1	LS	\$1,000.00	\$1,000.00
SUBTOTAL				\$1,000.00

<u><b>LABOR</b></u>				
TASKS	QUANTITY	UNIT	LABOR RATE	TOTAL COST
Mobilization	8	hr.	\$23.21	\$185.68
Travel	16	hr	\$23.21	<b>\$371.36</b>
Sample collection	50	hr.	\$23.21	\$1,160.50
Geologist	50	hr	\$23.21	\$1,160.50
SUBTOTAL				\$2,878.04
BURDENED				\$6,820.95

(Burden Rate = 2.37)

TOTAL LABOR, OPTION 4	\$6,820.95
TOTAL ODCS	\$3,788.34
TOTAL SUBCONTRACTS	\$24,156.00
AWARD FEE	\$2,046.03
<b>TOTAL COST</b>	<b>\$36,811.32</b>

**TABLE 3**  
**COST ESTIMATE OF INDIRECT COSTS FOR**  
**IN SITU AIR SPARGING TRENCH**

**INDIRECT COSTS**

Cost Items	Unit Costs	Units	Number Units	Unit Costs	Comment	Source
<b>DESIGN AND ENGINEERING</b>						
Project Manager	\$34.00	HR	64	\$2,176.00	8 hr/wk x 8	Baker
Civil Engineer	\$22.00	HR	160	\$3,520.00	40 hr/wk x 4	Baker
Cost Estimator	\$19.00	HR	20	\$380.00	20 hr/wk x 1	Baker
CAD operator	\$15.00	HR	20	\$300.00	20 hr/wk x 1	Baker
Word processor	\$11.00	HR	8	\$88.00	4 hr/wk x 2	Baker
<b>TOTAL DESIGN AND ENGINEERING</b>				<b>\$6,464.00</b>		
<b>CONSTRUCTION ADMINISTRATION AND DISTRIBUTIVE COSTS</b>						
<b>Personnel</b>						
Project Manager	\$34.00	HR	50	\$1,700.00	5 hr/wk x 10	OHM DL Rate
Site Superintendent	\$22.00	HR	80	\$1,760.00	40 hr/wk x 2	OHM DL Rate
Field Engineer	\$22.00	HR	80	\$1,760.00	40 hr/wk x 2	OHM DL Rate
Accountant	\$20.00	HR	12	\$240.00	3 hr/wk x 4 w	OHM DL Rate
Secretary/Typist	\$10.00	HR	20	\$200.00	2 hr/wk x 10	OHM DL Rate
Civil Engineer	\$22.00	HR	4	\$88.00	2 hr/wk x 2 w	OHM DL Rate
Q/C Engineer	\$22.00	HR	2	\$44.00	1 hr/wk x 2 w	OHM DL Rate
Purchasing Agent	\$25.00	HR	40	\$1,000.00	40 hr/wk x 1	OHM DL Rate
Mechanic	\$10.00	HR	10	\$100.00	5 hr/wk x 2 w	OHM DL Rate
Certified Hygienist	\$34.00	HR	8	\$272.00	4 hr/wk x 2 w	OHM DL Rate
Site Health & Safety Officer	\$19.00	HR	40	\$760.00	40 hr/wk x 1	OHM DL Rate
<b>Support Equipment/Facilities - Assume trailer and equipment will remain for 2 months as part of monitoring plant</b>						
Office Trailer	\$150.00	Mo	2	300		CTO 274 RAC
Copier & other office furniture	\$300.00	Mo	2	600		CTO 274 RAC
FAX	\$300.00	Mo	2	600		CTO 274 RAC
Equipment Trailer	\$150.00	Mo	2	300		Baker invoices
Portable Toilets	\$60.00	Mo	2	120		Baker invoices
Trash Dumpster	\$75.00	Mo	2	150		Baker invoices

**TABLE 3**  
**COST ESTIMATE OF INDIRECT COSTS FOR**  
**IN SITU AIR SPARGING TRENCH**

Cost Items	Unit Costs	Units	Number Units	Unit Costs			Comment	Source
Electric	\$75.00	Mo	2	\$150.00				Eng. Estimate
Phone	\$200.00	Mo	2	\$400.00				Eng. Estimate
Cell Phone	\$200.00	Mo	2	\$400.00				Eng. Estimate
Walkie -Talkies	\$30.00	Mo	2	\$60.00				Eng. Estimate
Expendables	\$2,000.00	EVENT	1	\$2,000.00				Previous jobs
Travel/PerDiem								
Lodging and meals	\$103.00	DAY	96	\$9,888.00				See below
Truck	\$52.00	DAY	48	\$2,496.00				
TOTAL CONSTRUCTION ADMIN/DISTRIBUTIVE COSTS				\$25,388.00				
SET UP COSTS								
Level Set Up Office Trailer	\$40.00	EACH	1	\$40.00				
Level Set Up Equipment Trailer	\$40.00	EACH	1	\$40.00				
Electric Hook-up	\$2,000.00	LS	1	\$2,000.00				
Phone Hook- up	\$5,000.00	LS	1	\$5,000.00				
Deliver Trash dumpster	\$200.00	EACH	1	\$200.00				
Utility Clearance OHM	\$8.00	HR	8	\$64.00				
Utility Clearance Subcontractor	\$55.00	HR	4	\$220.00				
TOTAL SET UP COSTS				\$7,564.00				
PER DIEM	Days 1 to 5	Days 5 to 10	Days 1 to 10	Ops Week 1	Ops Weeks 2 - 8	Ops Weeks 9 - 26	Total	
H & S Officer	5						5	
Supervisor			10				10	
Site Engineer			10				10	
Sampling Tech/Installer	5	5		2	7	5	24	
Sampling Tech/Installer	5	5		2	7	5	24	
Equip Operator	5		10				15	
Equip Operator	5						5	
Mobile Lab Operator	3						3	
Total	28	10	30	4	14	10	96	
Equipment Operators, 2 truck drivers and 1 backhoe operator for storm drain installation.								

**TABLE 4**  
**COST ESTIMATE, O & M LABOR AND ANALYTICAL COSTS**  
**IN SITU AIR SPARGING TRENCH**

Cost Items	Unit Cost	Units	No Units	Costs	Source
<b>LABOR FOR SAMPLING</b>					
Week 1	\$14.00	HR	60	\$840.00	Assume 2 techs - 3 events, 20 hrs per event
Week 2 - 8	\$14.00	HR	140	\$1,960.00	Assume 2 techs - 20 hrs per week, 1 event per week
Week 9 - 26	\$14.00	HR	80	\$1,120.00	Assume 2 techs - 4 events, 1 event per mo, 20 hrs per event
<b>TOTALS LABOR FOR SAMPLING</b>			<b>280</b>	<b>\$3,920.00</b>	
<b>SAMPLES ASSOCIATED WITH SAMPLING EFFORT</b>					
Week 1	\$150.00	Each	30	\$4,500.00	Engineering Estimate (VOAS only)
Week 2 - 8	\$150.00	Each	70	\$10,500.00	Engineering Estimate (VOAS only)
Week 9 - 26	\$150.00	Each	40	\$6,000.00	Engineering Estimate (VOAS only)
<b>TOTALS SAMPLING EFFORT</b>			<b>140</b>	<b>\$21,000.00</b>	

**APPENDIX B**  
**VENDOR INFORMATION**

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February 10, 1997

Mr. Mike Smith  
Baker Environmental  
Airport Office Park Building 3  
420 Rouser Road  
Coraopolis, PA 15108

Transmittal  
Geo-Con's Bio-Polymer Trench Construction Technique

Dear Mr. Smith:

In accordance with our conversation, I am pleased to forward the enclosed information describing Geo-Con's capabilities in the construction of Bio-Polymer trenches. Geo-Con has installed over 400 slurry walls throughout the United States since 1979. In addition, Geo-Con is the originator of the B-P drain method for installing interception/extraction drains for groundwater collection and waste remediation.

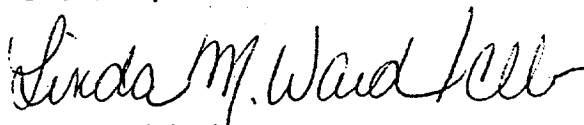
We have demonstrated expertise and experience in the successful performance of projects throughout the United States, working with private sector clients in the manufacturing, chemical, petroleum and pulp and paper industries and with government agencies. Our experience has led to the development of special slurry mixtures, custom-built equipment, and task-specific procedures to ensure the successful completion of our projects.

The B-P drain method results in significant savings in materials, dewatering, disposal, shoring, schedule and worker health risks. All work is performed from the ground surface using a bio-degradable slurry. The trench width is narrower than otherwise required, toxic volatilization is minimized or eliminated, and no workers will enter the trench. These advantages result in a much safer and less costly installation.

After reviewing the enclosed literature, please feel free to call me if you need additional information, such as spec sheets, or wish to discuss details of our services further. Thank you for your inquiry.

Sincerely,

GEO-CON, INC.



Linda M. Ward  
Regional Director  
Business Development

Enclosures

# DEEP DRAINAGE TRENCHES BY THE BIO-POLYMER SLURRY TRENCH METHOD

## Technical Brief

### Bio-Polymer Slurry Drainage Trench

Bio-Polymer Slurry Drainage Trenches (B-P Drain) are narrow, vertical trenches filled with permeable materials that act as interceptor drains or extraction trenches for the collection or removal of groundwater and groundwater-borne pollutants. B-P Drains are constructed using the slurry trench technique with a biodegradable carbohydrate instead of bentonite as the active ingredient in the water-based trenching slurry. The principal advantages of B-P Drains are their high groundwater transmissivity, rapid installation sequence, superior safety environment for workers, and relatively greater depth capability.

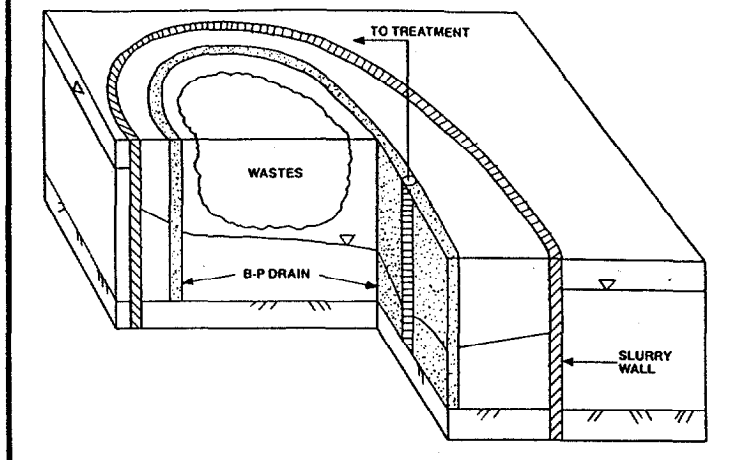
### APPLICATIONS

The first productive use of a B-P Drain was in the 1970's in Europe for the interception of groundwater near unstable highway slopes. It was found that a B-P Drain could effectively lower in-situ pore pressures by transmitting groundwater around the unstable slopes without the need for extensive dewatering, mass excavation and structural bracing.

In the United States, there has been a growing need for deep Drainage trenches to collect contaminated groundwater for treatment and disposal. Often these drains must be very deep and operated for extended periods in congested areas. Recent advances in the slurry trench equipment and biodegradable slurry additives have made the use of this technology both practical and cost-effective. B-P Drains are now economically competitive on projects where mass excavation, sheeted excavations and/or well points would have previously been used. Some recommended applications are to:

- stabilize earthen slopes,
- intercept contaminated

Schematic of Typical Bio-Polymer Slurry Drainage Trench



- groundwater plumes,
  - collect contaminated groundwater inside of waste containment landfills,
  - transmit groundwater around work areas,
  - hydraulically isolate lagoons or holding ponds.
- The B-P Drain installation combines the continuity and storage capacity of an interceptor pipe-drain with the ease of installation and depth capability of a deep well system.

### CONSTRUCTION

The construction sequence for the B-P Drain is similar to that used for slurry cut-off walls except that 1) permeable materials such as gravel or sand are used for the trench backfill, and 2) a biodegradable slurry is used in lieu of a bentonite clay slurry to support the excavation

without the use of lateral bracing.

B-P slurry trenches are installed by excavating a narrow trench (2 - 4 ft. wide) while simultaneously pumping in a biodegradable slurry and maintaining the level near the surface and above the surrounding groundwater table. The trench is then backfilled with permeable materials to form the permanent drainage system.

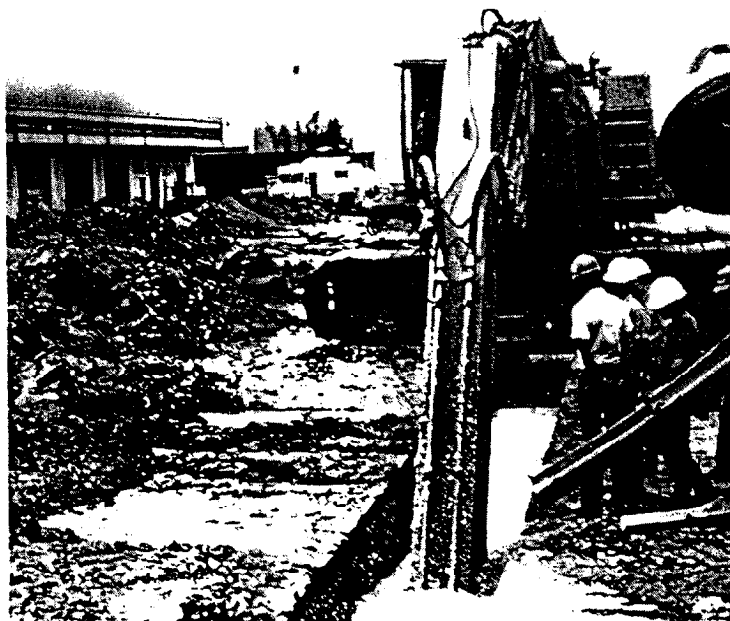
The critical ingredient in the B-P Drain is the biodegradable slurry. The active ingredient in the slurry is a natural bio-polymer which yields a pseudo-plastic fluid when slurried with water. A properly controlled and modified slurry will remain effective for one to two weeks before reverting back to water. Specially modified slurry mixing equipment is

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used to blend the bio-polymer, additives and water into an effective trenching slurry. Monitoring of the pH and viscosity of the slurry is required to maintain the stability of the slurry and thus the trench during excavation.

Once the trench is open and supported with slurry, a variety of permeable materials may be placed through the slurry into the trench. The simplest system is to fill the trench with gravel or a sand filter and grade the trench bottom to a collection point. In difficult soil, vertically graded filters may be tremied into the trench or filter fabrics sunk into the trench to resist invasion of soil into the drainage system. Well casings can be easily placed into the trench during excavation to provide groundwater extraction capabilities.

When the trench is completed, the remaining bio-polymer slurry is broken or converted back to water and a minute amount of natural dustuff (residual bio-polymer) which is quickly consumed by soil organisms. The breaking of the bio-polymer is accomplished either by natural enzymes in the soil or by the addition of a breaker solution. Once the slurry has been broken, the native soil formation surrounding the trench assumes its original hydraulic conductivity in a short time.

## DESIGN

The incorporation of a B-P Drain into any project requires a working knowledge of both the strengths and limitations of the technique. The primary design considerations for a B-P Drain are hydraulic conductivity, clogging resistance, collection and disposal options, slurry compatibility, and project application.

Hydraulic conductivity and clogging resistance are critical factors which are usually evaluated based on filter criteria with the surrounding soil and the required permeability of the drain. Typically a well-graded but freely draining sand or stone is used as the backfill. In difficult applications it may be necessary to incorporate a woven geotextile to the face of the trench to minimize the migration of fine soil particles into the drain.

Usually a collection point or extraction well is installed to collect groundwater. The groundwater can then be transmitted to an on-site treatment or storage facility. Well spacing, screen openings and casing dimensions are sized based on the filter material and performance expectations.

In order to have an effective slurry, it is necessary to have a reliable water source for slurry mixing. The fresh slurry may be preserved and



Well installation

modified with slurry additives for successful trenching and later broken with other additives. In general, a properly controlled slurry will be resistant to most saline or contaminated groundwater, though the slurry's effective lifetime may be shortened by some environmental factors such as temperature and soil-water chemistry.

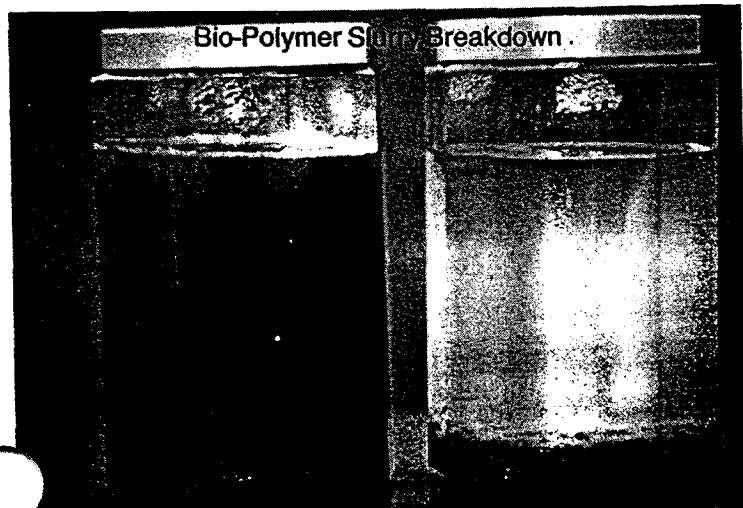
Typically, drainage trenches for waste containment are installed on the down-gradient side of waste containments. For stabilizing slopes, the drain is installed up-gradient of the slope. Pairs of drainage trenches may be installed on both sides of a contaminated zone to act as a recharge and collection system. A comprehensive understanding of groundwater patterns and the purpose of the drain is required for each project. In most cases, the depth of the drain is designed to intercept groundwater well below seasonal fluctuations. Drains may be installed to collect all

contaminated groundwater by extending the drain as deep as a natural aquiclude. In other cases, the groundwater sink created by the drain can be used to create a flow toward the well thus minimizing both the length and depth of the drain. B-P Drains may be combined with slurry walls to both contain and collect groundwater.

This type of system has obvious construction advantages as well as optimum flexibility in modifying groundwater patterns for the designer.

## CONCLUSION

Deep drainage trenches can be installed by the bio-polymer slurry trench method and are gaining recognition for use in slope stability and pollution control. This technique offers a cost-effective solution to many construction and design problems for drain installation. The economy and flexibility of the technique are being utilized on an increasing number of projects.



Active slurry

Slurry shortly after addition of breaker solution

# Phone Call Report

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Project/Location:	<u>MCB Camp Lejeune - Site 35</u>	S.O. No.:	<u>62470-323-1000-05000</u>
	<u>Interim Design for Groundwater</u>	Date:	<u>January 22, 1997</u>
		Contract No.:	<u></u>

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To:	<u>Dr. Paul Johnson</u>	From:	<u>Dan Bonk, Don Joiner, Mike Smith</u>
Repres.:	<u>ASU</u>	Repres.:	<u>Baker</u>
Phone No.:	<u>602-965-9115</u>	Phone No.:	<u></u>

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Subject: Dan Bonk reviewed the results of the treatability study and the status of the interim remedial design for Site 35. Dan noted that Baker was considering options for the design, and that a horizontal air sparging system was being considered. The following items were discussed:

1. Depth of air sparging system and method of installation - Dan noted that the depth of the air sparging system would be approximately 40 feet, and that we were considering both horizontal directional drilling and a trench design. Dan also noted that there are concerns about clay lenses, at depths less than 40 feet, in the area of concern that may affect the performance of the air sparging system. Paul noted that at this depth, it is difficult to determine if horizontal drilling or a trench is less costly. He did note that from an effectiveness standpoint, a horizontal air sparging header constructed in a trench (which is backfilled with a more permeable material than the surrounding soils), is the best way to insure that the horizontal air sparging system is effective as a "sparge wall".
2. Hydrogeologic considerations and trench design - Dan asked if a "sparge wall" in a trench arrangement could lead to a situation where the groundwater moves around the trench, and not through it. Paul said that this could happen if too much air is introduced into the trench, which essentially can make the trench zone less permeable, and that the air flow rate to the trench needs to be controlled so that this does not happen. We discussed the required width of the trench, and Mike Smith asked about any requirements for residence, or contact time, of the groundwater. Paul noted that trying to determine the exact trench width is not critical, because the slow groundwater velocities will provide more than adequate contact time between the groundwater and the air supply.
3. Review of specifications - Dan said he would like Paul to review Baker's specifications on the installation and monitoring of the air sparging system.
4. Air sparging header design considerations - We discussed general design considerations for the horizontal air header. Paul recommended that if it was possible, he would distribute air to the horizontal header through multiple

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Prepared by:	<u>Don Joiner</u>	Title:	<u>Senior Engineer</u>	Page:	<u>1</u>	of	<u>2</u>
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cc: DL Bonk; SJ Kretschman; MD Smith; MD Bartman; Project file

vertical drop pipes, which would be valved to provide control of the air supply. He suggested that the horizontal header be not less than 1-inch diameter, and not greater than 2-inches. Paul also noted that for a pilot test, an overall header length of 100 feet is probably adequate.

5. Bio-fouling - Mike asked about any potential concerns about bio-fouling within the trench. Paul said he did not think that bio-fouling would not be a problem because the growth of a bio-mass is rate limited depending on an available food supply. Since the groundwater velocities are slow, the transport of a food source is limited.

6. Migration of injected air - Mike asked if migration of the injected air is a concern with a trench type system. Paul indicated that with a trench, migration of the volatilized gases (outside the trench), would be unlikely.

# Air Sparging in Gate Wells in Cutoff Walls and Trenches for Control of Plumes of Volatile Organic Compounds (VOCs)

by James F. Pankow<sup>1</sup>, Richard L. Johnson<sup>2</sup>, and John A. Cherry<sup>b</sup>

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## Abstract

Volatile organic compounds (VOCs) can be stripped from ground water by sparging air into water in wells or in trenches. This well/trench sparging ("WTS") can remove VOCs from plumes of contaminated ground water as that water passes across the sparge zone. With sparging in wells, cutoff walls will be needed to force the contaminated water through the "gate" wells. With in situ sparging ("ISS"), air is sparged directly into a contaminated aquifer. ISS may be useful in treating local zones of high contamination, but WTS is better suited for treating large plumes of contaminated ground water. Interest in sparging methods is growing because: (1) they do not remove water from the subsurface, and so difficult disposal issues are avoided and an increasingly valuable water resource is not depleted; and (2) the Darcy velocity  $v$  in many systems is low, and so only a relatively small volume of water must be treated per unit time.

The theoretical fractional efficiency of WTS is given by  $E = S/(1 + S)$ . The parameter  $S$  is named here as the "dimensionless sparge number," with  $S = HR_g/(RTyzv)$  where  $H$  (atm-m<sup>3</sup>/mol) = Henry's Law constant for the compound of interest;  $R_g$  (m<sup>3</sup>/s, at 1 atm pressure) = gas sparging rate;  $R$  = gas constant ( $= 8.2 \times 10^{-5}$  m<sup>3</sup>-atm/mol-deg);  $T$  = temperature (K);  $yz$  (m<sup>2</sup>) = cross-sectional area producing the water which is passing into the sparging zone; and  $v$  = Darcy velocity (m/s).  $E$  increases as  $S$  increases.  $E$  increases as  $H$  increases because the volatility of a compound goes up as its  $H$  increases. Plots for  $E$  in WTS are given vs.  $S$  as well as vs. some of the variables making up  $S$ .

Well/trench sparging (WTS) has the potential to become a useful treatment method for removing VOCs from contaminated ground-water plumes. It is suited for use with most of the solvents and petroleum products which have caused extensive ground-water contamination. The theory of the method is simple, and the theoretical removal efficiencies are predictable as well as adjustable.

## 1 Introduction

### General

The contamination of ground water by volatile organic compounds (VOCs) remains an important environmental problem. VOCs of interest include many dense nonaqueous phase liquids ("DNAPLS," e.g., the chlorinated solvents), as well as the petroleum-related "BTEX" group (benzene, toluene, ethylbenzene, and the xylenes). Most current efforts to remediate or at least control VOC contamination involve pumping at purge wells. Accelerated in situ biodegradation has proven difficult on large scales, accelerated dissolution using micelle-forming surfactants is still under development, and aquifer excavation is usually far from

practical. With pumping at wells, the water may be: (1) discharged directly to a sewer; (2) treated and discharged to a sewer; or (3) treated and returned to the aquifer. With sewer discharge, an often only slightly contaminated natural resource is discarded. With aboveground treatment with subsequent return to the aquifer, there may be significant capital costs. Therefore, alternative treatment technologies remain of interest. This is especially the case for *plume control*, given that full remediation is often essentially impossible at many sites of interest.

It is natural to try and take advantage of the volatility of VOCs by designing aeration methods which remove them directly from the subsurface. Certainly vacuum extraction has been found useful in removing VOCs from the vadose zone. For the saturated zone, aeration can take place by two methods. In "sparging" in a well or a trench (abbreviated here as "WTS"), air is injected into liquid water at the bottom of an open well or trench (Figures 1a, 2a, 2b). The freely rising bubbles of air strip volatile compounds from the ground water that is flowing through the sparge zone. Depending on the situation, the VOCs in the gas generated by sparging may need treatment prior to release to the atmosphere. In an early application, Coyle et al. (1985) used

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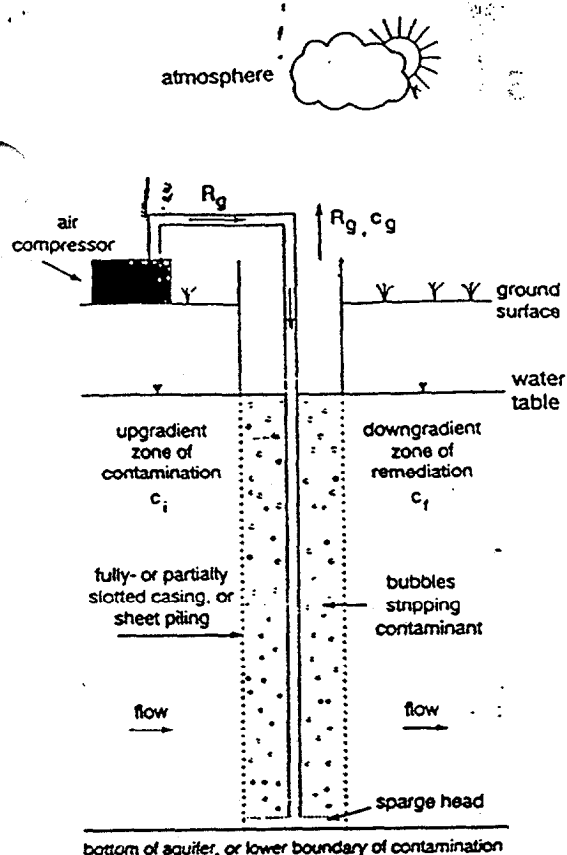


Fig. 1a. Sparging in a well, or in a trench ("WTS," cross-sectional view).

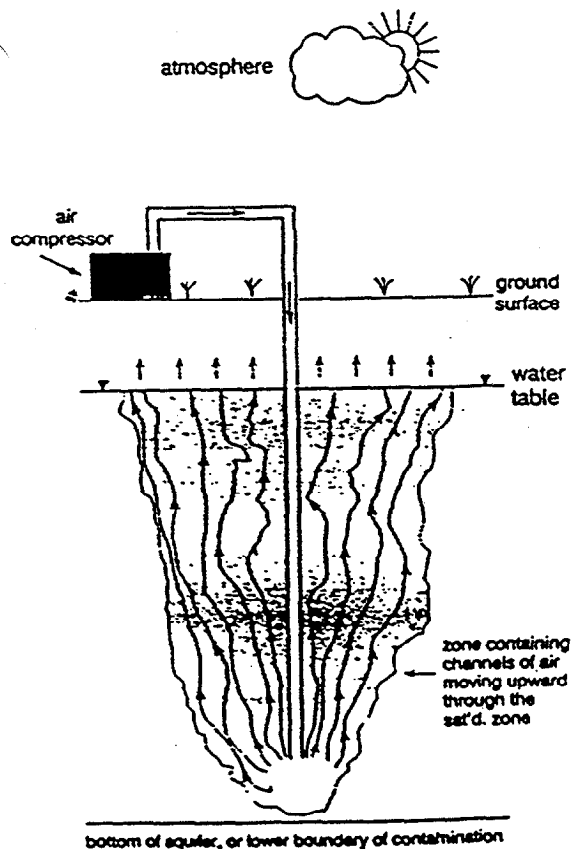


Fig. 1b. Direct air injection using in situ sparging ("ISS") in the saturated zone of an aquifer in a porous medium (cross-sectional view). Air moves upwards through channels (represented as lines) in the porous medium.

this form of sparging to pump water by "air lift" from a well, and at the same time, to strip VOCs so that the well could be used as a drinking water supply.

In contrast to WTS, in "in situ sparging" (ISS), air is injected directly into a saturated porous medium through an installed screen (Marley et al., 1992; Brown and Jasiulewicz, 1992) (see Figure 1b). VOCs are thereby removed directly from the aquifer. The gas flow generated by ISS can be coupled to a vacuum extraction operation involving the vadose zone. In sandy aquifers, at low ISS air injection rates, stable channels of air will be established in the medium; the air rising through the channels will remove VOCs from water in the adjacent pores, as well as from any volatile liquid product phase that might also be present in those pores. In coarse gravels, the injected air may rise as bubbles towards the water table. At high air injection rates in sandy, shallow, water-table aquifers, the possibility exists that the saturated zone near the injection point could become fluidized, with bubbles then rising towards the surface. ~~Fluidization of a portion of the aquifer in a zone where~~ a liquid organic contaminant is present could also cause a mobilization of that organic liquid. This can be helpful if the liquid is volatile because it will facilitate the vaporization process. However, ISS might also thereby lead to an increased rate of dissolution and transport away from the treatment zone, including possibly introducing small droplets of the liquid organic phase into the moving ground water.

### Site Remediation

The use of sparging in wells to remediate a site contaminated with VOCs has been suggested by Herrling et al. (1990), Herrling and Buermann (1990), and Gvirtzman and Gorelick (1992). The air lift induced by the sparging is used to pump water upwards for immediate reinfiltration. In the approach of Herrling et al. (1990) and Herrling and Buermann (1990), the reinfiltration occurs through a screen near the top of the well. In the approach of Gvirtzman and Gorelick (1992), the reinfiltration occurs through a circular gallery installed near ground surface. In both approaches, the reinfiltration creates a continuous circulation between the well and the aquifer. With each passage through the sparge well, the levels of the VOCs are reduced. As with other sparging methods, no net water is removed from the aquifer. Presumably, numerous of these recirculating sparge wells would be needed to remediate any real site. A disadvantage of this approach is that as the depth to the water table increases, the need to bring water close to the surface for distribution in the infiltration gallery will require sparge rates that are increasingly large. When examined on a mass of VOC stripped per unit volume of air basis, these rates may become unattractive.

Site remediation by ISS will probably be most attractive when there is high localized contamination significantly above the aquitard (if any), and when one knows the location of that contamination. For example, when liquid gasoline has been spread vertically in the saturated zone by an oscillating water table, ISS in the contaminated zone could be an efficient treatment method. In contrast, for more

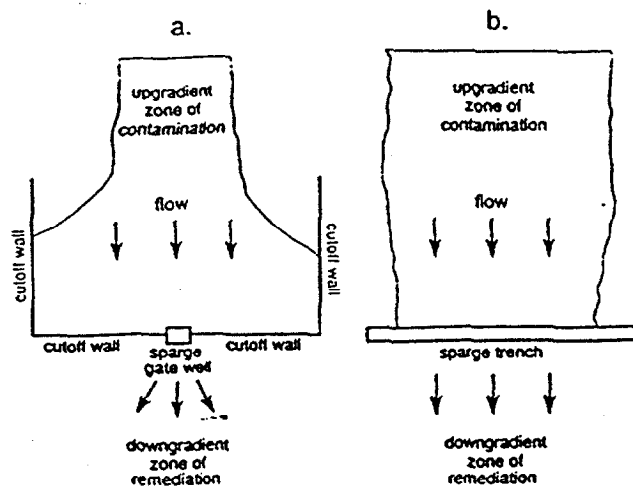


Fig. 2. a. Sparging in a gate well in a cutoff wall for interception and treatment of a flow of contaminated ground water (plan view). Note the tendency of the plume to widen behind the cutoff wall. b. Sparging in a rectangular trench for interception and treatment of a flow of contaminated ground water (plan view).

dispersed zones of VOC contamination, removal by ISS may be difficult because of inefficiencies in the transport of the VOCs to the injection zone. This may remain true even when those areas of contamination lie directly upgradient of the ISS area. Indeed, note that irregularities in the distribution of the air channels (at low ISS flow rates) or in the zones of fluidization (at high ISS flow rates in shallow sandy aquifers) may allow advected water to flow through the general area of the injection zone and yet miss exposure to the air channels. For sites at which a liquid DNAPL solvent is present in one or more pools directly on top of an aquitard, treatment of the ground water by ISS is not likely to be effective. Indeed, as shown by Johnson and Pankow (1992) and Anderson et al. (1992), dissolution from a DNAPL pool into the overlying ground water is normally very slow. In addition, it will be very difficult to get much direct ISS air contact with a DNAPL pool.

### Control and Remediation of a VOC Plume

When an entire VOC contamination site cannot be remediated in a cost-effective manner by any means, then long-term plume control is often the only remaining option. Preferably, this option will involve remediation of the ground water that does leave the area. ISS will probably not be useful in this mode because of irregularities in the air injection process. Sparging in a continuous trench in WTS, however, could be used to remove VOCs from a moving plume (Figure 2b). Under most natural ground-water flow conditions, the volume flux of water through an aquifer (given by the Darcy velocity) is quite small. In the types of unconfined sand or gravel aquifers that are prone to widespread contamination, typical volume fluxes are 0.015 to 0.50 m<sup>3</sup>/m<sup>2</sup>-day in the direction of flow (Darcy velocities of 0.015 to 0.5 m/day). This range corresponds to 0.010 to 0.35 liters/m<sup>2</sup>-min. Thus, even for aquifers that are tens of meters thick, the volume flow rate per meter of aquifer width is less than a few liters per minute. This is a relatively small rate in a treatment context.

A trench for WTS could be constructed using perforated, interlocking sheet-piling. After installing the two sheet-pile walls, the zone between the walls would be excavated and the gas lines for sparging installed. Since the concentration of the contaminant in the ground water arriving at the trench will surely vary along the length of the trench, it may also be advantageous to subdivide the cells along that length. The flow of sparge air could then be adjusted along the length of the system so that the majority of the air is applied where it is needed the most.

An alternative to an open sparge trench would be one that is backfilled with coarse gravel (or pebbles). Gravel-filled trenches can be installed using conventional technology. In the case of cohesive materials, direct excavation could be carried out. In the case of noncohesive materials, driven sheet-piling could be used. Following excavation, the air lines could be laid, and the zone backfilled with the desired material. This type of system would be easier to stabilize against caving than would an open sparge trench.

Sparging in wells could also be used to treat a plume, but in this mode, cutoff walls will surely be needed to force all of the contaminated flow into the sparge "gate well" (Figure 2a). The types of cutoff walls which could be used include conventional bentonite slurry walls installed by trenching, or the type of sealable, driven sheet-piling that has been described by Starr et al. (1992). Our field research indicates that gate wells can be constructed from a rectangle of perforated, interlocking sheet-piling that is, in turn, locked into the cutoff wall. Slotted baffles could divide the sparge zone into sequential cells (see below), with sparge heads placed at the bottom of each cell. If the cutoff wall is of interlocking, sealable sheet-piling, then the sparge zone could be locked directly into the cutoff wall. If the cutoff wall is of bentonite, the sheet-piling could be withdrawn after the sparge cell is installed, and the sparge gate sealed to the cutoff wall with additional bentonite.

Because of the tendency of the plume to build up and spread behind a cutoff wall, the plume width which a given system will be able to handle will be less when a cutoff wall/sparge gate(s) system is used than when a sparge trench is used. However, for a wide contaminant plume, a cutoff wall/sparge gate combination might be installed at less cost than a sparge trench. In order to prevent an excessive rise in the hydraulic head upgradient of the gated cutoff wall, results from our modeling work suggest that in the Figure 2a configuration, to avoid too much hydraulic head buildup, it will be necessary to have 5-20% of the wall as gates. The focus of this paper will be on the use of WTS for the control and remediation of VOC plumes.

### Historical Perspective on Sparging

Up until the mid 1980s, the development of sparging for use in either remediation or in plume control was inhibited by the view that it was easier to treat VOC contaminated water after it was removed from the subsurface. For example, the flow of the VOC-contaminated water can be controlled more easily, in pump and treat, and the energy requirements of pump and treat with cascade aeration are generally lower per volume of water treated than with sparg-



ing. With respect to the latter point, note that: (1) pumping a given volume  $V$  of air a distance  $h$  meters below the water table so as to create bubbles for sparging will take roughly the same amount of energy as pumping the same volume  $V$  of water a similar distance above the water table for cascade aeration; and (2) it is relatively inexpensive to blow large volumes of air against the low backpressures in an aeration tower, and so in cascade aeration, a given volume  $V$  of water can be exposed to a much larger volume of air for stripping the VOCs than can be accomplished using a volume  $V$  of air during well sparging. Therefore, from a simple point of view that considers only the cost-effectiveness of the treatment, assuming roughly similar capital equipment needs, pumping followed by cascade aeration will generally be more economical than well sparging.

Much has changed, of course, since the early 1980s. Now and for the foreseeable future, the simple economics of treatment is by far not the only consideration involved in deciding on treatment options. Issues of *public perception*, *regulatory policy on the disposal of contaminated water*, as well as a greatly increased *water resource value* have converged to make sparging much more attractive for use in plume control. For example, consider a ground-water plume that contains a mean concentration of trichloroethylene of  $100 \mu\text{g/l}$  (100 ppb). Let us say that a certain WTS sparging design is capable of reducing the mean concentration to the current U.S. EPA drinking water limit of  $5 \mu\text{g/l}$ . In many communities (especially those in the drier climates of the west), it might well be easier to win approval for this in situ, 95% efficient treatment approach than it would be to gain approval for a design which pumps the water from the ground, treats it with 95% efficiency, then: (a) injects or infiltrates the water, viewed as "still-contaminated" back into the aquifer, or (b) discards the resource into a surface stream or a sewer. Thus, the energy disadvantage of sparging can quickly become a nonissue. Furthermore, we note that pump and treat methods often draw uncontaminated water into the zone of contamination, and also that abilities of such methods to remove contaminants from an aquifer generally decrease in time.

### Plume Control and Remediation by Well/Trench Sparging (WTS)—Theory

Figure 3 is a schematic diagram of sparging taking place in a single gate well, or along a single trench across the zone of contamination. Due to difficulties in construction, a depth of  $\sim 50$  m probably represents an upper limit for the installation of WTS trench zones.

Sparging with air will lead to a saturation of the ground water with oxygen. When the water of interest is anoxic, this may lead to the problematic precipitation of iron and manganese oxyhydroxides in, as well as downgradient of, the sparge zone. Since contaminated ground water is frequently close to the ground surface, for the many systems of interest that are already largely oxic, there will be no such precipitation. Moreover, since biological degradation of some compounds is promoted by oxygen, raising the oxygen levels to saturation can be beneficial in further lowering the contamination that escapes removal by sparging. If oxygenation of

system can be carried out as described by Herrling et al. (1990). In that approach, the sparge air is recycled. Contaminants are cleaned from the air using activated carbon, and the cleaned air is reused. The anoxic water in the well quickly removes the oxygen from the air, and the sparging then continues using the nitrogen and other inert gases remaining in the air.

The theoretical efficiency of WTS in removing dissolved volatile contaminants from the water which actually passes through a sparge zone may be predicted using a constant flow, stirred tank reactor (CFSTR) approach (e.g., see Levenspiel, 1972). The predictions require a knowledge of the Henry's Law constant  $H$  ( $\text{atm}\cdot\text{m}^3/\text{mol}$ ) for the compound of interest, the gas sparging rate  $R_g$  ( $\text{m}^3/\text{s}$ , at 1 atm pressure), the cross-sectional area  $yz$  ( $\text{m}^2$ ) producing the water which is passing into the sparging zone, and the Darcy velocity  $v$  ( $\text{m/s}$ ).

Zone A in Figure 3 represents the portion of an aquifer that is contaminated at the dissolved concentration  $c_i$  ( $\text{mols}/\text{m}^3$ ) with a VOC. When Zone A is characterized by a range of concentrations, the volume-averaged mean concentration entering Zone B should be used as  $c_i$ . Zone B is the well-mixed, open well (or trench) in which single stage sparging is occurring. (The manner in which the removal efficiency can be increased by distributing  $R_g$  over several sequential stages is discussed below.) The concentration in Zone B is  $c_f$  ( $\text{mols}/\text{m}^3$ ). Zone C is the zone of the aquifer that is receiving the treated ( $c_f$ ) water. The use of a single  $c_f$  value to describe the concentration in the sparging zone results from the assumption that the sparging zone is well-mixed. Bubble zones in liquid water columns are indeed well-mixed vertically, and the level of in-column dispersion increases with the sparge gas flow rate (Siemes and Weiss, 1959). The

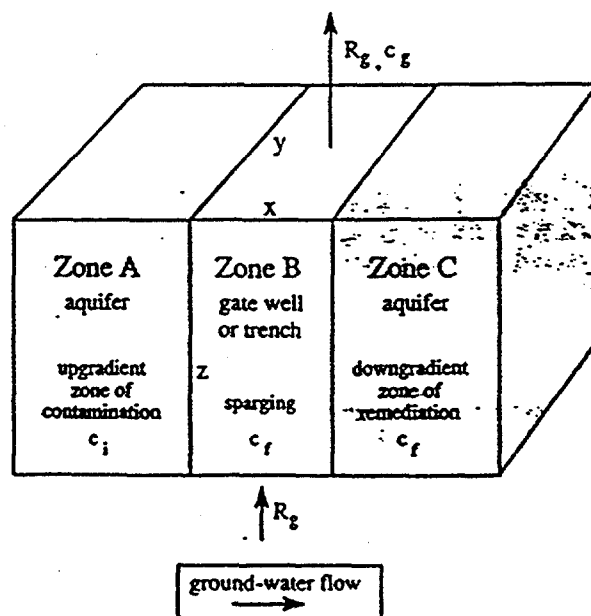


Fig. 3. Model for contaminant removal by sparging with a single stage. Contamination at concentration  $c_i$  in the upgradient portion of the aquifer (Zone A) is lowered in the sparging zone (Zone B) to  $c_f$  before flowing into the downgradient portion of the aquifer (Zone C) at concentration  $c_f$ .

bubbles in Zone B will pose essentially no resistance to flow through the zone.

At steady state,  $c_i$  is constant in time. The groundwater volume flux ( $\text{m}^3/\text{m}^2\text{-s}$ ) is given by the Darcy velocity  $v$  ( $\text{m/s}$ ). In units of  $\text{mols/s}$ , the mass balance for a given VOC on the sparging zone is then

$$c_{i,yz}^{\text{in}} = c_{i,yz}^{\text{out}} + c_g R_g \quad (1)$$

where  $yzv$  is the water volume flow rate into and out of the sparging zone, and  $c_g$  is the concentration ( $\text{mols}/\text{m}^3$ ) of the VOC in the sparge gas leaving the sparging zone. In the case of a gate well in cutoff wall,  $y$  is the effective capture width of the gate well. According to the Ideal Gas Law,

$$c_g = n/V = p/RT \quad (2)$$

where  $n/V$  = number of mols of volatilized contaminant per  $\text{m}^3$  of sparge gas,  $p$  is the partial pressure of the contaminant in the sparge gas ( $\text{atm}$ ),  $R$  is the gas constant ( $= 8.2 \times 10^{-5} \text{ m}^3\text{-atm}/\text{mol-deg}$ ), and  $T$  is the temperature ( $\text{K}$ ). Note that if  $t$  is the temperature in degrees centigrade, then  $T = t + 273.15$ .

In WTS, it may be expected that equilibrium will be nearly established in the sparge zone between the ground water and the sparge gas. The equilibrium relationship between the partial pressure of a gas and its aqueous concentration is given by Henry's Law as

$$p = H c_i \quad (3)$$

The larger the value of  $H$ , the greater the volatility of the compound. Using an approach discussed by Gvirtzman and Gorelick (1992), it can be shown that except for high sparge rates, the equilibrium for VOCs represented by equation (3) will in fact be attained. Fair et al. (1973) also discuss this matter in considerable detail.

By equations (1)-(3),

$$c_{i,yz}^{\text{in}} = c_{i,yz}^{\text{out}} + (H c_i / RT) R_g \quad (4)$$

$$c_i / c_i = 1 / [1 + H R_g / (RT yzv)] \quad (5)$$

We define  $S$  as a dimensionless "sparge number":

$$S = H R_g / (RT yzv) \quad (6)$$

so that in the ideal case,

$$c_i / c_i = 1 / (1 + S) \quad (7)$$

The theoretical ideal fractional efficiency  $E$  of the WTS process is given by

$$E = 1 - c_i / c_i \quad (8)$$

$$= S / (1 + S) \quad (9)$$

The larger  $S$  is, the more efficient is the removal. Thus,  $E$  increases with increasing  $H$  since the volatility of a compound goes up as its  $H$  value increases. Increasing  $R_g$  will also increase  $E$ . Increasing  $y$ ,  $z$ , and  $v$ , however, both decrease  $E$  since they increase the volume rate of addition of contaminated water to the sparging zone. The dependence of  $E$  on  $R_g$ ,  $y$ ,  $z$ , and  $v$  is contained in the dependence of  $E$  on  $R_g / yzv$ , the dimensionless air to water ratio. Since a given

zone or subzone of contamination under treatment will be characterized by specific values of  $y$ ,  $z$ , and  $v$ , then for that zone or subzone of the parameters making up  $R_g / yzv$ , only  $R_g$  may be adjusted to improve  $E$ .

We note that in the ideal, theoretical case, the volume of the zone  $xyz$  in which WTS is occurring does not affect  $E$ ; changing  $x$  does not alter the ratio of the volume rate of addition of sparge gas to the volume rate of addition of contaminated water. For example, while doubling  $x$  doubles the hydraulic residence time in the sparge zone, and so one might expect an increase in  $E$ , the volume of water which  $R_g$  must treat is also doubled, and so  $E$  remains unchanged. The fact that  $E$  is independent of  $x$  indicates that  $x$  can be varied so as to avoid difficulties associated with trying to force too much air through too little water.

Table 1 summarizes  $H$  data for the 20-25°C range for a variety of compounds of interest. In the case of the contamination of an aquifer with more than one compound, to the extent that the different compounds possess different  $H$  values, they will be removed with different efficiencies. In addition to being compound-dependent,  $H$  values are also temperature-dependent, often increasing by a factor of  $\sim 2$  for every 10 degree increase in temperature. Use of the Table 1 data at temperatures other than 20-25°C should be made cautiously. Therefore, if the Table 1 data are used when the ground water is cooler than 20-25°C, the calculations will produce best-case  $E$  values. As noted by Collins (1925), the mean temperature of ground water in the United States ranges between 5°C and 25°C. If  $H(288.15 \text{ K})$  is the value of  $H$  at  $T = 288.15 \text{ K}$  (15°C), then at this temperature

$$S = H(288.15 \text{ K}) R_g / (0.024 yzv) \quad (10)$$

An increasing amount of information is becoming available giving the  $T$ -dependence of  $H$  values for VOCs of interest (e.g., Hunter-Smith et al., 1983; Gossett, 1986). Whenever possible,  $H$  values for the exact temperature of interest should be employed. Sometimes, literature values for  $H$  are expressed as dimensionless air to water concentration ratios (i.e., in our notation, they are sometimes expressed as  $H/RT$  values); to convert to the units used here ( $\text{atm-m}^3/\text{mol}$ ), multiply by  $RT$  ( $= 0.024 \text{ atm-m}^3/\text{mol}$  @ 288.15 K).

The criterion for inclusion in Table 1 was a minimum  $H$  value of  $8 \times 10^{-3} \text{ atm-m}^3/\text{mol}$ . Approximately half of the organic EPA "priority pollutants" are in Table 1. Most of the data are reliable. However, as with all equilibrium constants, the accuracies of calculations made based on such data depend upon the reliabilities of the constants themselves. Note that the  $H$  values reported for the PCBs are mixture-average values. As such, they are not true thermodynamic constants, and should only be used as general indicators of the behavior of these PCB mixtures.

All of the petroleum-related monocyclic aromatic compounds are relatively volatile. This fact is very positive from the viewpoint of sparging gasoline-contaminated ground waters. Although not included in Table 1, it may be noted in the same regard that aliphatic compounds (found at very high concentration in gasoline) possess very large  $H$  values (Mackay and Shiu, 1981), and moreover are only sparingly soluble in water in the first place.

Table 1. Henry's Law Constants ( $H$ , atm-m<sup>3</sup>/mol) for Selected Organic Compounds  
[Data Obtained from Mabey et al. (1982) and Mackay and Shiu (1981)]

Compound	$H$	$t$ (°C <sup>a</sup> )	Compound	$H$	$t$ (°C <sup>a</sup> )
<b>Chlorinated Nonaromatics</b>			<b>Monocyclic Aromatics, continued</b>		
Methyl chloride	0.04	20	Hexachlorobenzene	0.00068	20/25
Methyl bromide	0.20	20	Toluene	0.0067	20
Methylene chloride	0.0020	20/25	Ethylbenzene	0.0066	20
Chloroform	0.0029	20	<i>o</i> -Xylene	0.0050	25
Bromodichloromethane	0.0024	20/22	<i>m</i> -Xylene	0.0070	25
Dibromochloromethane	0.00099	20/22	<i>p</i> -Xylene	0.0071	25
Bromoform	0.00056	20	1,2,3-Trimethylbenzene	0.0032	25
Dichlorodifluoromethane	3.0	25	1,2,4-Trimethylbenzene	0.0059	25
Trichlorofluoromethane	0.11	20	1,3,5-Trimethylbenzene	0.0060	25
Carbon tetrachloride	0.023	20	Propylbenzene	0.0070	25
Chloroethane	0.15	20	Isopropylbenzene	0.0013	25
1,1-Dichloroethane	0.0043	20	1-Ethyl-2-methylbenzene	0.0043	25
1,2-Dichloroethane	0.00091	20	1-Ethyl-4-methylbenzene	0.0050	25
1,1,1-Trichloroethane	0.03	25	<i>n</i> -Butylbenzene	0.013	25
1,1,2-Trichloroethane	0.00074	20	Isobutylbenzene	0.033	25
1,1,2,2-Tetrachloroethane	0.00038	20	<i>sec</i> -Butylbenzene	0.014	25
Hexachloroethane	0.0025	20/22	<i>tert</i> -Butylbenzene	0.012	25
Vinyl chloride	0.081	25	1,2,4,5-Tetramethylbenzene	0.025	25
1,1-Dichloroethene	0.19	25/20	1-Isopropyl-4-methylbenzene	0.0080	25
1,2- <i>trans</i> -Dichloroethene	0.067	20	<i>n</i> -Pentylbenzene	0.0060	25
Trichloroethene	0.0091	20	<b>Pesticide and Related Compounds, and PCBs</b>		
Tetrachloroethene	0.0153	20	Ethylene dibromide (EDB) <sup>b</sup>	0.00082	25
1,2-Dichloropropane	0.0023	20	<i>trans</i> -Chlordane	0.000094	25
<i>trans</i> -1,3-Dichloropropene	0.0013	20/25	Heptachlor	0.0040	25
Hexachlorocyclopentadiene	0.016	25	Heptachlor epoxide	0.00039	25
Hexachlorobutadiene	0.026	20	2,3,7,8-TCDD	0.0021	—
<b>Chlorinated Ethers</b>			Aroclor 1016 <sup>c</sup>	0.00033	25
Bis(chloromethyl)ether	0.00021	20 25	Aroclor 1221 <sup>c</sup>	0.00017	25
Bis(2-chloroisopropyl)ether	0.00011	20	Aroclor 1242 <sup>c</sup>	0.0020	25
4-Chlorophenylphenylether	0.00022	25	Aroclor 1248 <sup>c</sup>	0.0036	25
4-Bromophenylphenylether	0.00010	20/25	Aroclor 1254 <sup>c</sup>	0.0026	—
<b>Monocyclic Aromatics</b>			<b>Polycyclic Aromatics</b>		
Benzene	0.0055	25	Naphthalene	0.00046	25
Chlorobenzene	0.0036	20/25	Acenaphthene	0.000091	25
<i>o</i> -Dichlorobenzene	0.0019	20	Acenaphthylene	0.0015	20/25
<i>m</i> -Dichlorobenzene	0.0036	25	Anthracene	0.000086	25
<i>p</i> -Dichlorobenzene	0.0031	25	Phenanthrene	0.00023	25
1,2,4-Trichlorobenzene	0.0023	25			

<sup>a</sup>Where two temperatures are given, the first is the temperature at which the vapor pressure was measured, and the second is the temperature at which the solubility was measured.

<sup>b</sup>Vapor pressure data from Stull (1947), and solubility data from Stephen and Stephen (1963).

<sup>c</sup>Mixture-average value.

When the Table 1 pesticides and related compounds, PCB formulations, and polycyclic aromatic compounds are present in soils containing nontrivial amounts of organic carbon, they will not be expected to move very rapidly (Karickhoff, 1984). However, in porous media of very low organic carbon (e.g., sands and gravels), and when soil particles and/or emulsions of liquid are facilitating the sub-surface transport of such compounds, their degrees of retardation will be smaller, and plume control by WTS sparging may be of interest.

While all of the compounds in Table 1 are at least somewhat volatile from water, some are substantially more volatile than others. E.g., dichlorodifluoromethane is 35,000 times more volatile from water than is anthracene. The dependence of  $E$  upon  $S$  is illustrated in Figures 4 and 5.

Efficient removal by sparging is possible for low  $H$  compounds for a given  $v$  value by adjusting  $S$  through the manipulation of  $R_g/yz$ . As with many treatment processes, achieving  $E = 0.90$  is relatively easy ( $S = 9$ ). Each additional incremental increase in  $E$ , however, becomes increasingly difficult. Thus, an  $S$  value of 99 is required for  $E = 0.99$ , and an  $S$  value of 999 is required for  $E = 0.999$ .

The fact that equation (9) and Figures 4 and 5 represent what may be expected in an actual sparging situation is supported by consideration of the well-understood gas-exchange process as discussed by Fair et al. (1973) and Gvirtzman and Gorelick (1992). These conclusions have been verified for sparging on a laboratory scale by Pankow and Johnson (1985). In that study, 1,1,1-trichloroethane and 1,1,2-trichloroethane were removed from a simulated aqui-

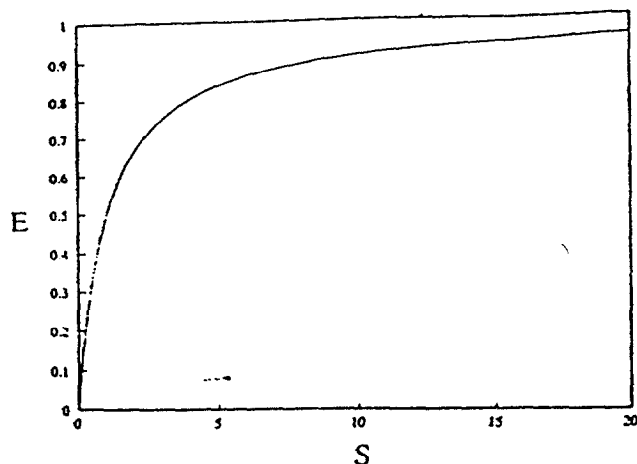


Fig. 4. Sparging efficiency  $E$  vs.  $S$  for single stage sparging with  $S$  ranging from 0 to 20.

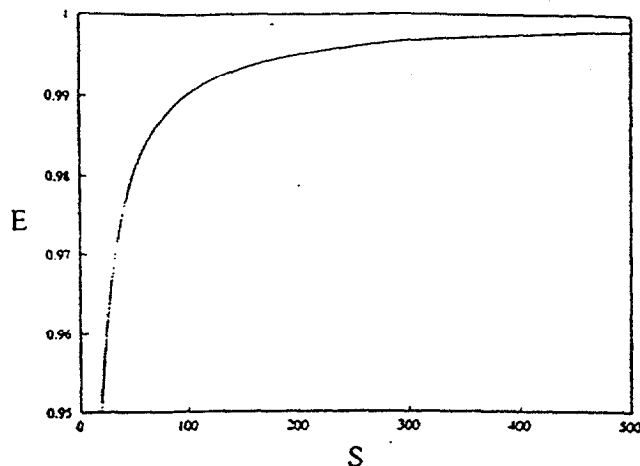


Fig. 5. Sparging efficiency  $E$  vs.  $S$  for single stage sparging with  $S$  ranging from 20 to 500.

fer system by WTS. The predicted  $E$  values for these two compounds under the experimental conditions used were 0.997 and 0.892, respectively. These values agree very well with the measured efficiencies of 0.994 and 0.946, respectively. A field sparging investigation which supports equation (9) is provided by the work of Coyle et al. (1985) using WTS for the removal of VOCs from a drinking water well while using "air lift" to pump the water to the surface.

While Figures 4 and 5 represent dimensionless plots for the determination of  $E$  for any combination of the variables comprising  $S$ , Figures 6-8 allow the examination of how  $E$  depends upon specific values of three variables. For each figure, a moderate value for one of the variables has been selected and kept constant, and the other two have been varied: one on the abscissa, and one by means of a family of curves. Since equation (10) was used to calculate  $S$ , a temperature of  $15^\circ\text{C}$  (288.15 K) has been assumed. Because the explicit dependence of  $S$  on  $T$  is weak, Figures 6-8 will

provide good estimates of  $E$  at other temperatures provided that  $H$  values which are correct for the temperature of interest are used, that is, provided that the stronger, implicit temperature dependence of  $H$  is taken into consideration. For Figures 6 and 7, where  $H$  is varied as a family of curves, the positions of lines for certain specific compounds at  $15^\circ\text{C}$  are indicated.

As seen in Figure 6,  $E$  increases with increasing  $R_g/yzv$ . However, for all  $H < 0.00043 \text{ atm}\cdot\text{m}^3/\text{mol}$  (e.g., naphthalene), then  $E \leq 0.90$  when  $R_g/yzv \leq 500$ . For a given value of  $yzv$ , a larger gas sparging rate  $R_g$  will then be needed; for  $yzv = 0.0001 \text{ m}^3/\text{s}$  (e.g.,  $y = 10 \text{ m}$ ,  $z = 10 \text{ m}$ , and  $v = 10^{-6} \text{ m/s}$  (8.6 cm/day), we would need  $R_g \geq 0.05 \text{ m}^3/\text{s}$ . We note that 50 hp compressors are available which will deliver  $10^6$  cubic feet/day ( $0.33 \text{ m}^3/\text{s}$ ) against a pressure of 15 psig ( $\sim 10 \text{ m}$  of water column head). With this  $R_g$  and with  $yzv = 0.0001 \text{ m}^3/\text{s}$ , the  $R_g/yzv = 3300$ , and even an  $H$  value of only  $0.0002 \text{ atm}\cdot\text{m}^3/\text{mol}$  will yield  $E > 0.95$ . With terminal bubble rise velocities of  $\sim 0.25 \text{ m/s}$ , however, this type of  $R_g$  would not be compatible with sparging in gate wells of conventional size since a well I.D. of 1.3 m would be required to accommodate the air alone. Sparging in a trench or in a large gate well made of perforated sheet-piling could then be used. (At the water surface, the fraction  $f$  ( $0 \leq f \leq 1$ ) of the sparging volume (of cross section  $A \text{ m}^2$ ) occupied by bubbles can be approximated by  $f = R_g/[A(0.25 \text{ m/s})]$ .) In difficult cases, sparging in multiple, sequential stages to obtain efficiency multiplication may be attractive (see below).

Figure 7 presents curves of  $E$  vs.  $yzv$  for  $R_g = 0.05 \text{ m}^3/\text{s}$ . The lowest  $H$  values considered permit significant removal at  $yzv = 0.0001 \text{ m}^3/\text{s}$ , and high  $E$  values are obtained for the very volatile compounds. Figure 8 is similar to Figure 7 except that here  $H$  is held constant at a fairly low value ( $0.0003 \text{ atm}\cdot\text{m}^3/\text{mol}$ ), and  $R_g$  is varied. As usual, high values of  $E$  are obtained for large  $R_g$  and small  $yzv$ .

The final plot of interest is one which summarizes the conditions under which a certain constant  $E$  is obtained. How large  $E$  must be in a given situation will, of course, depend upon the absolute magnitude of  $c_i$ . For  $E = 0.95$ ,

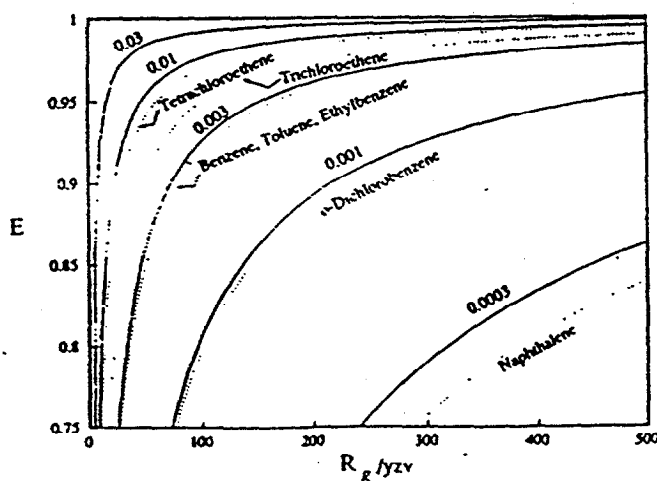


Fig. 6. Sparging efficiency  $E$  vs.  $R_g/yzv$  at  $t = 15^\circ\text{C}$  for single stage sparging for varying  $H$  values.

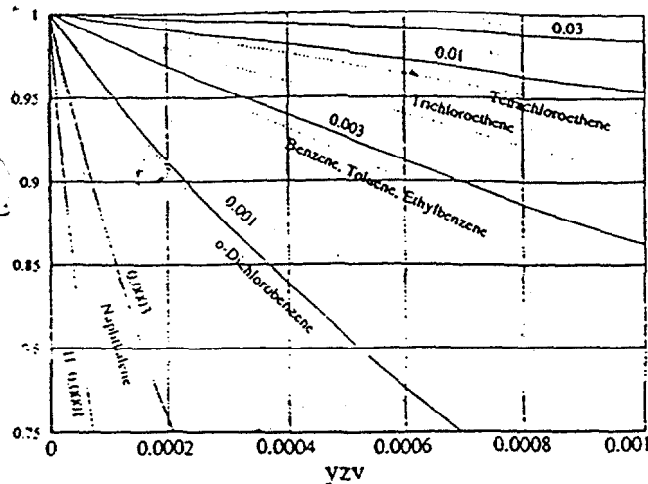


Fig. 7. Sparging efficiency  $E$  vs.  $yzv$  at  $t = 15^\circ\text{C}$  for single stage sparging for varying  $H$  values, with  $R_g$  held constant at  $0.05\text{ m}^3/\text{s}$ .

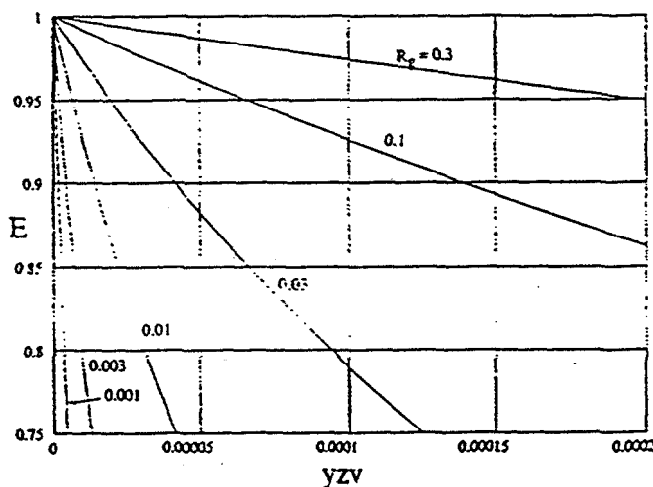


Fig. 8. Sparging efficiency  $E$  vs.  $yzv$  at  $t = 15^\circ\text{C}$  for single stage sparging for varying  $R_g$  with  $H$  held constant at  $0.0003\text{ atm-m}^3/\text{mol}$ .

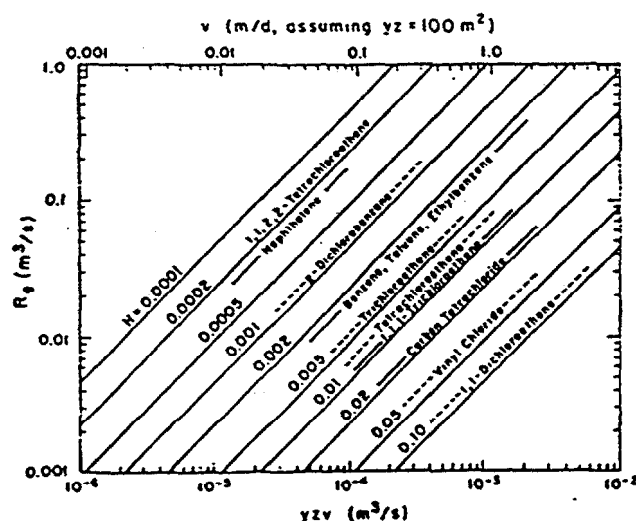


Fig. 9.  $R_g$  vs.  $yzv$  lines at  $t = 15^\circ\text{C}$  which yield  $E = 0.95$  for single stage sparging for varying  $H$  values. Top margin of plot labelled in terms of the Darcy velocity  $v$  in units of  $\text{m/d}$ , assuming  $yz = 100\text{ m}^2$ .

then by equation (7),  $R_g$  is given by equation (6),

$$R_g = 0.45 yzv/H \quad (11)$$

The  $R_g$  vs.  $yzv$  lines in Figure 9 have been drawn using equation (11) for varying values of  $H$ . This plot reveals the relative ease or difficulty of applying gate/well sparging under a wide range of conditions. (For purposes of comparison with specific situations, the top margin of the figure has been labelled in terms of  $v$  in units of  $\text{m/d}$ , assuming a  $yz$  value of  $100\text{ m}^2$ .) Thus, as  $yzv$  increases, the value of  $R_g$  required to maintain  $E = 0.95$  also increases for a given  $H$  value. Also, for a given  $R_g$  and  $E = 0.95$ , the value of  $yzv$  that can be tolerated increases as  $H$  increases. As an example, for  $E = 0.95$  and  $yzv = 10^{-3}\text{ m}^3/\text{s}$  ( $v = 0.86\text{ m/d}$  when  $yz = 100\text{ m}^2$ ), if  $H = 0.01\text{ atm-m}^3/\text{mol}$ , we require an  $R_g$  value of  $0.045\text{ m}^3/\text{s}$ .

### Sequential Sparging

The sparging efficiency  $E$  can be increased dramatically if the ground water is made to flow through several separate sparge cells in series rather than just through a single sparge cell. Since sparging is based on a linear gas/water partitioning process, each cell will remove contaminants with an efficiency which is independent of the contaminant concentration. The result will be a theoretical removal efficiency which is higher than that which is attainable with a single cell using the same total sparge gas flow rate.

When  $S \ll 1$ , then  $E$  increases approximately linearly with  $R_g$ . In the useful range of efficiencies ( $E > 0.5$ ), we need  $S > 1$ . Based on Figure 4, as  $S$  approaches 1, however,  $E$  increases only slowly with  $R_g$ . Consider then a single cell sparging system in which  $S = 10$  so that  $E \approx 0.9$ . Increasing  $E$  to 0.99 can be achieved by increasing  $R_g$ , but about 10 times the gas flow is required. However, splitting the gas flow among several different sparge cells is a much more efficient way to use the increased flow rate of sparge gas.

Consider then a series of sparge cells each of which removes a given VOC with a fractional efficiency of  $E$ . The amount remaining after passing through the first sparge cell is  $(1 - E)$ ; the amount remaining after passing through the second sparge cell is  $(1 - E)^2$ . Thus, the cumulative efficiency of  $n$  sequential cells is given by:

$$E_{\text{cum}} = 1 - (1 - E)^n \quad (12)$$

We can compare the relative improvements in the overall removal efficiency obtained by using a single sparge cell vs. sequential sparge cells. For example, if in a single-cell system  $E = E_{\text{cum}} = 0.50$  (i.e.,  $S$  in that cell is 1), then tripling the flow in that single cell will raise  $E_{\text{cum}}$  to 0.75. However, distributing that tripled flow over three sequential cells will raise  $E_{\text{cum}}$  to 0.875, and the amount of the VOC remaining in the water is half that when  $E_{\text{cum}} = 0.75$ . As another example, if in a single-cell system  $E = E_{\text{cum}} = 0.80$  (i.e.,  $S$  in for that cell is 4), then distributing the exact same flow over two sequential cells will increase  $E_{\text{cum}}$  to 0.89 ( $S = 3$  in each cell). This again reduces the amount of the VOC remaining in the water by a factor of about two. Given the low Darcy velocities present in many systems, single-cell sparging efficiencies of  $> 0.9$

should be attainable fairly easily. Therefore, a sequence of three or four such sparge cells in either a gate well or in a trench would result in very high removal efficiencies.

### Atmospheric Contamination Considerations Emissions to the Atmosphere

As is the case with aeration stripping carried out above the ground surface, sparging will produce contaminated air. If  $E = 0.95$ , and if  $c_i'$  is the initial concentration of the contaminant in mg/l, then the discharge in metric tons/year (t/y) will be

$$D_g = 30 yzvc_i' \quad (13)$$

It is of interest to examine how  $D_g$  for an extensively contaminated system will scale with other inputs to an urban airshed. Take  $c_i' = 50 \text{ mg/l}$  ( $= 50,000 \text{ } \mu\text{g/l}$ ) as summed over all of the volatile contaminants present. For  $y = 100 \text{ m}$ ,  $z = 20 \text{ m}$ , and  $v = 10^{-6} \text{ m/s}$  (8.6 cm/day), then  $D_g = 3.0 \text{ t/y}$ . While this may seem large in absolute terms, it is in fact not large relative to typical urban sources of volatile organic compounds (VOCs). The following are common, current emission rates: large gasoline station with vapor recycle emission controls, 2 to 3 t/y; clothing dry cleaners, 5 t/y (tetrachloroethene); large industrial "stoddard solvent" dry cleaners, 40 t/y; large industrial degreasers, 40 t/y. While the situations in individual locales vary, in general, discharge permits are often not currently necessary until the emissions rise above  $\sim 10 \text{ t/y}$ . Moreover, the  $D_g$  values at many ground-water contamination sites will be even lower since the total amounts of volatile contaminants present in whole ground-water systems are often less than a few metric tons. In general then, unless the political climate is relatively strict, the emissions from sparging are not likely to require regulatory attention. When the discharges are either high or inherently toxic, options that remain include: (1) acquisition of a discharge permit; or (2) treatment of the sparge air effluent prior to discharge, e.g., by sorption onto activated carbon.

### Effects of Contaminants Already Present in the Urban Atmosphere

A result of normal industrial emissions of VOCs is nonzero ambient air concentrations. Thus,  $E$  as predicted by equation (9) for WTS will not be fully attainable if the compound of interest is present in the sparge air even before the air enters the sparging zone. The decrease in efficiency may be predicted based on a mass balance approach similar to that used to derive equation (9). In this case,

$$\text{mols into sparging zone/s} = c_i yz v + c_a R_g \quad (14)$$

where  $c_a$  is the ambient air concentration (mols/m<sup>3</sup>). It may then be shown that

$$E = \frac{S}{1 + S} (1 - c_a RT/Hc_i) \quad (15)$$

The term  $(1 - c_a RT/Hc_i)$  is thus a correction factor for equation (9). It incorporates the ratio between: (1) the aqueous concentration with which  $c_a$  would be in equilib-

rium (i.e.,  $c_a RT/H$ ); and (2)  $c_i$ . For urban Portland, Oregon, Ligocki et al. (1985) reported the following gas phase concentrations in ambient air (mols/m<sup>3</sup>): trichloroethene,  $1.1 \times 10^{-8}$ ; tetrachloroethene,  $7.3 \times 10^{-9}$ ; toluene,  $4.1 \times 10^{-8}$ ; ethylbenzene,  $1.2 \times 10^{-8}$ ; and *o*-xylene,  $1.2 \times 10^{-8}$ . Thus, even when ground water which is only contaminated at the  $1 \text{ } \mu\text{g/l}$  level is treated,  $E$  will not be reduced significantly below that given by equation (9) except under those situations when the sparge air intakes are positioned (carelessly) near a localized atmospheric contaminant source.

Two final situations are of interest. When  $(1 - c_a RT/Hc_i)$  is less than zero,  $E$  will be negative, and sparging will cause  $c_i$  to be greater than  $c_i$ . In a similar manner, when  $c_i$  is zero for a given compound and its  $c_a$  is nonzero, then sparging will lead to ground-water contamination where there was none before. When problematic, both of the cases are likely to occur only for compounds that are not the direct target of the sparging. However, the resultant levels of contamination will generally be extremely low, and not the subject of concern.

### Conclusions

Well/trench sparging (WTS) has the potential to become a useful treatment method for removing VOCs from contaminated ground-water plumes. It is suited for use with a very large number of the solvents and petroleum products which have caused extensive ground-water contamination. The theory of the method is simple, and the theoretical removal efficiencies are predictable as well as adjustable. The advantages of the method include the facts that: (1) since the Darcy velocity  $v$  in many systems is relatively low, only a relatively small volume of water must be treated per unit time; (2) the water is not removed from the aquifer; and (3) unlike large-scale pumping and treat, it does not draw large volumes of uncontaminated water into the zone of contamination, nor does it mix large volumes of uncontaminated water with contaminated water prior to treatment. Plans are now being made to test well/trench sparging at the Borden field site.

### Acknowledgment

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### References

- Anderson, M. R., R. L. Johnson, and J. F. Pankow. 1992. Dissolution of dense chlorinated solvents into ground water: 1. Dissolution from a well-defined residual source. *Ground Water*, v. 30, pp. 250-256.
- Brown, R. A. and F. Jasiulewicz. 1992. Air sparging: A new model for remediation. *Pollution Engineering*, July, pp. 52-55.
- Collins, W. D. 1925. Temperature of water available for industrial use in the United States. U.S. Geological Survey Water-Supply Paper 520-F, pp. 97-104.
- Coyle, J. A., H. J. Borchers, Jr., and R. J. Miltner. 1985. Control of volatile organic chemicals in groundwater by in-well

- aeration. Proceedings, American Water Works Assoc., Annual Conference, Washington, DC. (June 1985).
- Fair, J. R., D. E. Steinmeyer, W. R. Penney, and J. A. Brink. 1973. Liquid-gas systems. Section 18 of Chemical Engineer's Handbook, Fifth Edition. McGraw-Hill, New York. pp. 18-1 to 18-96.
- Gossett, J. M. 1987. Henry's Law constants as a function of temperature. *Environmental Science and Technology*. v. 20, pp. 202-208.
- Gvirtzman, H. and S. M. Gorelick. 1992. The concept of in-situ vapor stripping for removing VOCs from groundwater. *Transport in Porous Media*. v. 8, pp. 71-92.
- Herrling, B., W. Buermann, and J. Stamm. 1990. In-situ remediation of volatile contaminants in groundwater by a new system of "underpressure-vaporizer-wells." In *Proceedings Conf. Subsurface Contamination by Immiscible Fluids*, Calgary, April 18-20, 1990, K. U. Weyer (ed.). A. A. Balkema, Publisher, Rotterdam.
- Herrling, B. and W. Buermann. 1990. A new method for in-situ remediation of volatile contaminants in groundwater—numerical simulation of the flow regime. *Proceedings VIII Int. Conf. Computational Methods in Water Resources*, Venice, June 11-15, 1990.
- Hunter-Smith, R. J., P. W. Balls, and P. S. Liss. 1983. Henry's Law constants and the air-sea exchange of various low molecular weight halocarbon gases. *Tellus*. v. 35B, pp. 170-176.
- Johnson, R. L. and J. F. Pankow. 1992. Dissolution of dense chlorinated solvents into groundwater. 2. Source functions for pools of solvent. *Environmental Science and Technol.* v. 26, pp. 896-901.
- Karickhoff, S. W. 1984. Organic pollutant sorption in aquatic systems. *J. Hydraulic Engineering*. v. 110, pp. 707-735.
- Levenspiel, O. 1972. *Chemical Reaction Engineering*. 2nd Edition. Wiley, New York. 578 pp.
- Ligocki, M. P., C. Leuenberger, and J. F. Pankow. 1985. Trace organic compounds in rain. 2. Gas scavenging of neutral organic compounds. *Atmos. Environ.* v. 19, pp. 1609-1617.
- Mabey, W. R., J. H. Smith, R. T. Podoll, H. L. Johnson, T. Mill, T.-W. Chou, J. Gates, I. W. Partridge, H. Jaber, and D. Vandenberg. 1982. Aquatic Fate Process Data for Organic Priority Pollutants. EPA Report No. 440/4-81-014.
- Mackay, D., W. Y. Shiu, and R. P. Sutherland. 1979. Determination of air-water Henry's Law constants for hydrophobic pollutants. *Environ. Sci. Technol.* v. 13, pp. 333-337.
- Mackay, D. and W. Y. Shiu. 1981. A critical review of Henry's Law constants for chemicals of environmental interest. *J. Phys. Chem. Ref. Data*. v. 10, pp. 1175-1199.
- Marley, M. C., D. J. Hazebrouck, and M. T. Walsh. 1992. The application of in-situ air sparging as an innovative soils and ground water remediation technology. *Ground Water Monitoring Review*. Spring, pp. 137-145.
- Pankow, J. F. and R. L. Johnson. 1985. A laboratory validation of in-situ sparging. Oregon Graduate Institute. Unpublished work.
- Siemes, W. and W. Weiss. 1959. The liquid mixing in bubble columns. *Dechema Monographien*. v. 32, p. 451.
- Starr, R. C., J. A. Cherry, and E. S. Vales. 1992. A new type of steel sheet piling with sealed joints for groundwater pollution control. *Proceedings 45th Canadian Geotechnical Conference*, Toronto, Ontario, October 16-28.
- Stephen, H. and T. Stephen (eds.). 1963. *Solubilities of Inorganic and Organic Compounds*. MacMillan, New York. v. 1, pt. 1, p. 381.
- Stull, D. R. 1947. Vapor pressures of pure substances. *Organic compounds*. *Indust. Eng. Chem.* v. 39, pp. 517-519.

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development and protection of ground-water supplies."

Individual membership dues in the Association of Ground Water Scientists and Engineers of \$82 per year (\$97 international) include a subscription to *Ground Water*, *Ground Water Monitoring Review*, and *The Newsletter of the Association of Ground Water Scientists and Engineers*. Membership application forms are available upon request.

National Ground Water Association, Inc.  
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**APPENDIX C**  
**FEBRUARY 1997 INVESTIGATION REPORT**

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The Baker logo consists of the word "Baker" in a white, sans-serif font, set against a solid black rectangular background.

**Baker Environmental, Inc.**  
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June 6, 1997

Commander  
Atlantic Division  
Naval Engineering Facilities Command  
1510 Gilbert Street (Bldg. N-26)  
Norfolk, Virginia 23511-2699

Attn: Ms. Katherine Landman  
Navy Technical Representative  
Code 08232

Re: Contract N62470-89-D-4814  
Navy CLEAN, District III  
Contract Task Order (CTO) 0323  
Pre Interim Remedial Investigation Field Activities  
OU No. 10 (Site 35) - Camp Geiger Area Fuel Farm  
MCB, Camp Lejeune, North Carolina

Dear Ms. Landman:

This letter has been prepared by Baker Environmental, Inc. (Baker) to present the results of the soil and groundwater sampling efforts conducted during the week of February 24, 1997 along the western right-of-way (ROW) boundary of the proposed U.S. Highway 17 Bypass in the vicinity of the former Camp Geiger Fuel Farm and Buildings TC474 and TC473. The purpose of this effort was to gather location-specific data to support the design and construction of the Phase I Remedial Action at Site 35, Camp Geiger Area Fuel Farm. The work was performed in accordance with the concurrence letter dated February 20, 1997. This letter report is comprised of the following sections: Background; Objectives; Field Investigation; Results; Conclusions; and Recommendations. Additional data is provided to support the text in Attachments A through D. These include: Attachment A-Figures; Attachment B-Tables ; Attachment C-Laboratory Data and Chain-of-Custody Sheets; and Attachment D- Boring Logs.

## **BACKGROUND**

In February, 1997 Baker submitted the 100% Design Package for the Phase I Interim Remedial Action (Phase I) at Site 35. This deliverable is the precursor to the Final Design Package for a horizontal in situ air sparging (IAS) system that will be located on the western right-of-way boundary of the proposed U.S. Highway 17 Bypass. A critical task associated with the 100% design was establishing a specific location for Phase I construction activities. Based on the location of solvent-related contamination plumes identified in the Remedial Investigation (RI), approximate location of the proposed western U.S. Highway 17 Bypass right-of way boundary, and limitations posed by existing roadways and active buildings, Baker identified two potential specific locations for Phase I construction activities that are shown in Figure I, and described below.



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- Area 1 is situated in the vicinity of the former above-ground storage tanks (ASTs) and fuel unloading pad. The proposed site is flat, easily accessible, does not interfere with Activity operations and will require limited utility relocation, if at all. No demolition activities would be required at this location, and the implementation of Phase I construction activities would not be impacted by highway construction activities. However, the levels of solvent-related groundwater contamination observed during the RI in Area 1 (100 ug/L) are substantially lower than the levels observed in Area 2 (1,000 ug/L).
- Area 2 is situated in the vicinity of Buildings TC474 and TC473. Both of these facilities are currently active and will remain in service until the commencement of demolition activities associated with the construction of U. S. Highway 17 Bypass. An area with total solvent-related groundwater contamination of 1,000 ug/L, identified during the RI, is located underneath these buildings and adjacent roadways and parking lots. This location is optimal for the implementation of Phase I construction activities, with respect to groundwater contamination. However, the implementation of Phase I construction activities at this location will require the demolition of these facilities. These facilities are scheduled for demolition during November 1997, to make way for the U.S. Highway 17 Bypass. However, discussions with the North Carolina Department of Transportation (NCDOT) indicated that demolition activities could be delayed unless wetlands issues associated with the construction of the Bypass are resolved.

Based on the uncertain commencement date of demolition activities in Area 2, Area 1 was tentatively selected in the 100% design as the proposed location for the implementation of Phase I construction activities. The final selection of a site for Phase I construction activities will be based on an assessment of current groundwater contamination levels, and location specific geological data identified in Areas 1 and 2 collected during the Pre-Interim Remedial Action field activities. These additional field activities were approved by LANTDIV via a Baker concurrence letter dated February 20, 1997 and commenced on February 21, 1997.

## OBJECTIVES

The overall objective of this field effort was to gather sufficient geological and groundwater contamination data that would support the assessment of both Area 1 and Area 2 as potential locations for the implementation of Phase I construction activities. The specific objectives of the field activities were as follows:

- Establish, via survey, the exact location of the western ROW boundary of the proposed U.S. Highway 17 Bypass in the vicinity of Site 35.
- Gather sufficient geological data to determine the elevation of the confining unit.
- Identify any clay lenses or strata that could potentially impact the design and implementation of an in situ air sparging system.
- Determine the current levels of fuel and solvent-related groundwater contamination.

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## **FIELD INVESTIGATION**

Field activities commenced on February 21, 1997. Prior to the installation of any temporary monitoring wells, the western ROW boundary of the proposed U.S. Highway 17 Bypass was surveyed and staked in the field between "C" Street and the new pumping station, by Lanier Surveying Inc. of Jacksonville, NC (Figure 2). Upon completion of surveying activities a discrepancy was noted between the approximate ROW shown in Figure 1 and the actual alignment shown in Figure 2. The actual alignment of the western right-of way boundary in the field was approximately 15 to 30 feet to the west of the approximate ROW boundary alignment shown in Figure 1 in the vicinity of Area 1. The discrepancy between the actual and approximate ROW alignment in the vicinity of Area 2 was somewhat less than that.

The ROW discrepancy resulted in changes to Task 2 - Monitoring Well Installation and Task 3 - Groundwater Sampling and Analysis, that were outlined in the Baker concurrence letter dated February 20, 1997. The existing wells that were to be sampled, and the temporary well locations that were proposed in the concurrence letter are shown in Figure 1. The actual locations of the temporary wells and the existing permanent wells that were sampled are shown in Figure 2. In general, the differences between proposed and actual field activities that resulted from the ROW discrepancy are as follows:

- Intermediate temporary well TW34B was originally to be installed on the north side of Fourth Street adjacent to permanent monitoring well cluster MW22. This well was actually installed on the south side of Fourth Street closer to monitoring well cluster MW26 than MW22.
- The existing monitoring well MW22A was the shallow well that was originally paired with the intermediate temporary well TW34B. However, the actual location of TW34B was closer to existing monitoring well MW26A. As a result, MW26A was sampled as the shallow complement to TW34B rather than MW22A.
- Temporary monitoring well TW35B was originally to be installed north of the parking lot on the north side of Building TC474. The actual location of this temporary well is in front of Building TC474 on the eastern edge of "G" Street. Monitoring well MW27 remained as the shallow complement to TW35B.
- Temporary monitoring well cluster TW36A,B was originally to be installed on the south side of Building TC474. The actual location of this cluster is along the north side of Building TC473.
- Temporary monitoring well cluster TW37A,B was shifted to the west only a few feet.

### **Monitoring Well Installation**

A total of 10 temporary monitoring wells were installed to assess existing groundwater contamination in the upper and lower portion of the surficial aquifer during the week of February 24, 1997. These temporary monitoring wells were constructed as four, two well clusters (TW32A,B, TW33A,B, TW36A,B, and TW37A,B), and two individual wells (TW34B and TW35B). A cluster consisted of a shallow well, screened across the water table and an intermediate well that was seated in the confining unit. Shallow wells are designated with an A, and intermediate wells are designated with a B. Both single wells were constructed as intermediate wells. Shallow wells were constructed to depths that ranged from 16 feet below ground surface (bgs) to 18 feet bgs. Intermediate wells were constructed to depths that ranged from 45 feet bgs to 46 feet bgs. Well depths and screened intervals are summarized in Table 1.

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The temporary monitoring well borings were advanced using a 3 1/4-inch ID hollow stem augers. Upon reaching depth, a 1" nominal diameter monitoring well was installed in the borehole through the auger. No sand pack, bentonite seal, or protective casings were installed with any of the temporary monitoring wells. During monitoring well construction it was necessary to introduce water into the borehole to maintain borehole integrity and combat heaving sands.

The temporary monitoring wells were constructed with Schedule 40, PVC, 1-inch nominal diameter screens (.01 slot) and riser pipe. Each monitoring well was also fitted with a well sock that acted as a filter. To be consistent with previous well installations at Site 35, intermediate wells were constructed with five-foot screens seated in the confining unit, and shallow wells were screened across the water table with ten-foot screens.

Under Task 2- Monitoring Well Installation, a subsurface soil investigation was conducted that consisted of a geological classification of subsurface soils that are underneath Areas 1 and 2. Under this task splits spoons were collected during the advancement of intermediate depth well borings (TW32B, TW33B, TW34B, TW35B, TW36B and TW37B). Split spoons were collected continuously in borings TW32B, and TW33B. The geology observed in these borings, by the site geologist, was noted to be consistent with the geology identified at adjacent existing borings. As a result split spoons were collected at five-foot centers in borings TW34B, TW35B, TW36B, and TW37B. Split spoons were not collected from shallow well borings. No environmental soil samples were collected for analysis. Upon completion of groundwater sampling activities, the well screens and riser pipes were removed from the boreholes, and the open boreholes were backfilled with cuttings.

### Groundwater Sampling and Analysis

Under Task 3-Groundwater Sampling and Analysis, groundwater samples were collected from all ten temporary monitoring wells (TW32A,B, TW33A,B, TW34B, TW35B, TW36A,B, and TW37A,B) and two existing permanent monitoring wells (MW26A and MW27A) using a peristaltic pump that was capable of operating in the low-flow mode. Tubing through which the sample was collected was dedicated to each well and discarded after each use. Prior to sample collection each well was purged until all of the following criteria were met:

- A minimum of three well volumes were removed from each well.
- Conductivity and pH readings from three consecutive well volumes that were within 10% of each other.
- Turbidity readings of 10 nephelometric turbidity units (NTUs) or less were observed.

Groundwater samples were packed on ice and shipped to Weston Environmental Metrics Inc., of University Park, Illinois for Contract Lab Protocol (CLP) Volatile Organic Analysis (VOA).

### Management Of Investigative Derive Waste (IDW)

Cuttings generated during the investigation were placed on plastic and covered. After completion of the sampling program the cuttings were used to backfill boreholes. As a result no solid IDW remained at the site after the completion of the field effort.

Approximately 250 gallons of liquid IDW was generated during sampling operations. This is currently being stored in a 500 gallon tank currently located at Site 35. Upon approval from the Activity, LANTDIV and OHM Corporation this IDW will be transported to the groundwater treatment plant located at Site 82 along with liquid IDW from Sites 89 and 93.

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## **RESULTS**

The results of the subsurface soil and groundwater investigation are presented below. A geological cross-section that extends approximately from the tree line near the former above ground storage tanks (AST) to the south side of Building TC473 (Figure 3) is presented in Figure 4. Groundwater contamination data is presented in Table 2 and graphically depicted on Figures 5 through 8.

### **Subsurface Soil Investigation**

The geology that underlays Areas 1 and 2 is generally consistent with the geology observed from other borings advanced in the northern area of Site 35 during the RI. The top layer of soil across Area 1 and 2 is approximately 21 to 26 feet thick, and generally consists of a fine to medium sand with trace to little amounts of silt and clay. An intermediate layer of soil was observed between the top layer and the Castle Hayne confining unit. This layer is approximately 18 to 23 feet thick, and consists of a fine to coarse grain sand, cemented nodules and a trace of silt. In general, the Castle Hayne confining unit was identified at a depth of 41 to 44 feet bgs.

A layer of dark brown peat was observed in Area 1 in the soil borings associated with monitoring wells TW33B and TW34B. The top of the peat layer was observed at a depth of approximately 16 to 18 feet bgs. It extended to a depth of 25 and 26 feet bgs.

No significant clay lenses or strata that could potentially impact the design and implementation of an IAS system were encountered.

### **Groundwater Investigation**

The results of this investigation are presented in the following sections. Results are also presented in Table 2 and graphically in Figures 5 through 8.

#### **Non Site Related Contamination**

Compounds associated with the chlorination of potable water were detected in three samples. Chloroform was detected in samples 35-TW33A-05 (2 J ug/L), 35-TW36A-05 (6 J ug/L) and 35-TW35B-05 (3 J ug/L), and bromodichloromethane was detected in sample 35-TW36A-05 (4 J ug/L). Chloroform and bromodichloromethane are not associated with previous site activities that occurred at Site 35, and are typically found in temporary monitoring wells where substantial amounts of potable water was used during well installation.

#### **Site Related Contamination**

The site-related contamination data that was gathered during this investigation will be used to support the Final Design Package for an IAS system that is to be constructed at Site 35. Because the data is being used to support design and not a risk assessment the following sections focus on groups of contaminants (fuel-related and solvent-related contamination) rather than individual contaminants. In addition, the data from this investigation was organized in this manner so it could easily be compared to the RI data.

This investigation, considered total fuel-related contamination in a sample to be the sum of detected levels of benzene, toluene, ethylbenzene, and xylenes (total). Solvent-related contamination at this site consists only of the chlorinated hydrocarbon variety. As such, the total solvent-related contamination in a sample gathered under this investigation is the sum of detected levels of 1,1-dichloroethane, 1,1-dichloroethene, 1,1,2-dichloroethane,

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1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, trichloroethene, 1,2-dichloroethene (total) and vinyl chloride. During this investigation not all of the above fuel and solvent-related compounds noted above were detected. However, all of these contaminants were also used to define fuel and solvent-related contamination in the RI. In order to compare the data from this investigation to RI data, the same definitions of fuel and solvent-related data must be used. Nondetected chlorinated or fuel-related compounds were assigned a value of zero.

The analytical results are presented by area in the following sections. Within each area the results are presented by the lower and upper portion of the surficial aquifer, and compared to the results of the Baker RI.

#### Area 1

Contamination within Area 1 detected in this investigation was solvent-related, and limited to the lower portion of the surficial aquifer. Total solvent-related contamination levels ranged between 100 ug/L and 500 ug/L. Inconsistencies were noted between the data gathered during this investigation and the RI conducted by Baker in 1994, with respect to fuel-related contamination in the upper and lower portions of the surficial aquifer. Solvent-related contamination levels were generally consistent across both investigations.

##### Upper Portion of the Surficial Aquifer

No fuel or solvent-related contaminants were encountered in the upper portion of the surficial within the limits of Area 1 during this investigation (Figures 5 and 6).

With respect to total fuel-related contamination in the upper portion of the surficial aquifer, the results of this investigation are inconsistent with the results of the RI (Figure 5). Samples collected during the current investigation from the two shallow temporary wells (TW32A and TW33A) located within the limits of Area 1 exhibited no detections of fuel-related contamination. However, RI data indicated that temporary well TW32A was located in an area with total fuel-related contamination that ranged between 100 ug/L and 1,000 ug/L, and temporary well TW33A was located in an area that exceeded 1,000 ug/L of total fuel-related contamination.

These inconsistencies can potentially be explained by source removal activities that occurred during the summer and fall of 1995. Petroleum contaminated soils were removed and the excavations backfilled with clean soil within the footprint of the AST facility, and in an area east of F Street, adjacent to the parking area located north of building G480.

With respect to total solvent-related contamination in the upper portion of the surficial aquifer, the results from this investigation are consistent with the results of the RI (Figure 6). No solvent-related contamination was detected within the limits of Area 1 in the upper portion of the surficial aquifer during the RI or this investigation (Figure 6).

##### Lower Portion of the Surficial Aquifer

No fuel-related contamination was detected in the lower portion of the surficial aquifer within the limits of Area 1 during this investigation (Figure 7). However, total solvent related-contamination was detected in the two intermediate temporary wells (TW32B = 177 ug/L and TW33B = 296 ug/L) located within the limits of Area 1 and, a single intermediate temporary well (TW34B = 237 ug/L) located immediately south of the limits of Area 1 (Figure 8).

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The total solvent related-contamination detected in temporary well TW32B consisted of vinyl chloride (4 J ug/L), total 1,2-dichloroethene (170 ug/L), and trichloroethene (3 ug/L). The total solvent related-contamination detected in temporary well TW33B consisted of vinyl chloride (6 J ug/L), and total 1,2-dichloroethene (290 ug/L). The total solvent related-contamination detected in temporary well TW34B consisted of vinyl chloride (5 J ug/L), total 1,2-dichloroethene (210 ug/L), and trichloroethene (22 ug/L).

With respect to total fuel-related contamination in the lower portion of the surficial aquifer, the results of this investigation are somewhat inconsistent with the results of the RI. Samples collected under the current investigation from the two intermediate temporary wells (TW32B and TW33B) located within the limits of Area 1 exhibited no detections of fuel-related contamination. However, RI data indicated that temporary wells TW32B and TW33B were located in an area with total fuel-related contamination that was approximately 50 ug/L.

However, the total fuel-related results from intermediate temporary well TW34B that was located immediately south of Area 1 are consistent with RI data. Data collected during the RI and this investigation exhibited no fuel-related contamination in the immediate vicinity of this well location.

With respect to total solvent-related contamination in the lower portion of the surficial aquifer, the results from this investigation are consistent with the results of the RI (Figure 8). Data collected during the RI and this investigation indicated that in the vicinity of intermediate temporary monitoring wells TW32B, TW33B and TW34B total solvent-related contamination generally ranged between 100 ug/L and 300 ug/L.

## Area 2

Contamination within Area 2 was primarily solvent-related and was detected in both the upper and lower portions of the surficial aquifer. Total solvent-related contamination levels ranged between 30 ug/L and 900 ug/L. Inconsistencies were noted between the data gathered during this investigation, and the RI conducted by Baker in 1994 with respect to total fuel-related contamination in the lower portions of the surficial aquifer. Total solvent-related contamination levels throughout the surficial aquifer and fuel-related contamination in the upper portion of the surficial aquifer were generally consistent across both investigations with a few limited exceptions.

### Upper Portion of the Surficial Aquifer

Total fuel-related contamination in the upper portion of the surficial aquifer within Area 2 was limited to a single detection of xylene in a shallow temporary well (TW36A = 4 J)(Figure 5). However, total solvent related-contamination was detected in the two shallow temporary wells (TW36A = 608 ug/L and TW37A = 33 ug/L) located within the limits of Area 2.

The total solvent related-contamination detected in temporary well TW36A consisted of vinyl chloride (3 J ug/L), total 1,2-dichloroethene (450 ug/L), trichloroethene (110 ug/L), 1,1,2-trichloroethane (4 ug/L), and 1,1,2,2-tetrachloroethane (41 ug/L). The total solvent related-contamination detected in temporary well TW37A total 1,2-dichloroethene (22 ug/L) and trichloroethene (11).

With respect to total fuel-related contamination in the upper portion of the surficial aquifer, the results of this investigation are generally consistent with the results of the RI (Figure 5). Data collected during this investigation and RI data indicated that in the vicinity of temporary wells TW36A and TW37A, and permanent well MW27A, total fuel-related contamination was less than 10 ug/L.

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With respect to total solvent-related contamination in the upper portion of the surficial aquifer, the results from this investigation are also generally consistent with the results of the RI with the exception of a single sample that was collected from temporary well TW36A. Data collected during the RI and this investigation indicated that in the vicinity of temporary well TW37A total solvent-related contamination was less than 100 ug/L, and in the vicinity of MW27A no solvent-related contamination was detected.

RI data indicated that in the vicinity of TW36A no solvent-related contamination was detected. However, the sample collected from TW36A during the current investigation exhibited 608 ug/L of total solvent-related contamination.

#### Lower Portion Of the Surficial Aquifer

No total fuel-related contamination was detected in the lower portion of the surficial aquifer within the limits of Area 2 (Figure 7). However, total solvent related-contamination was detected three intermediate temporary wells (TW35B = 801 ug/L, TW36B = 886 ug/L and TW37B = 148 ug/L) located within the limits of Area 2 (Figure 8).

The total solvent related-contamination detected in temporary well TW35B consisted of vinyl chloride (8 J ug/L), total 1,2-dichloroethene (500 ug/L), and trichloroethene (290). The total solvent related-contamination detected in temporary well TW36B consisted of vinyl chloride (6 J ug/L), total 1,2-dichloroethene (400 ug/L, and trichloroethene (480 ug/L). The total solvent related-contamination detected in temporary well TW37B consisted of vinyl chloride (2 J ug/L), total 1,2-dichloroethene (81 ug/L), and trichloroethene (65 ug/L).

With respect to total fuel-related contamination in the lower portion of the surficial aquifer, the results of this investigation are somewhat inconsistent with the results of the RI. Samples collected under the current investigation from all three intermediate temporary wells (TW35B, TW36B, and TW37B) located within the limits of Area 2 exhibited no detections of fuel-related contamination. However, RI data indicated that temporary wells TW36B and TW37B were located in an area with total fuel-related contamination that exceeded 100 ug/L, and temporary well TW35B was located in an area with total fuel-related contamination that ranged between 50 ug/L and 100 ug/L. This inconsistency can also be explained by source removal.

With respect to total solvent-related contamination in the lower portion of the surficial aquifer, the results from this investigation are generally consistent with the results of the RI with the exception of a single sample that was collected from intermediate temporary well TW37B. Data collected during this investigation and RI data indicated that in the vicinity of temporary monitoring wells TW35B, TW36B and TW37B total solvent-related contamination was on the order of magnitude of 1,000 ug/L. This is consistent with contamination levels detected during the current investigation at monitoring wells TW35B and TW36B. However, a sample collected from temporary well TW37B exhibited 148 ug/L of total solvent-related contamination.

#### **CONCLUSIONS**

Considering the background information and data that was gathered during the Pre Interim Remedial Investigation field activities the following conclusions can made:

##### **Area 1**

- The commencement date of bypass demolition activities will not impact Area 1.



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- Fuel related contamination in the surficial aquifer, within the limits of Area 1, has been potentially impacted by the removal of petroleum contaminated soils in the vicinity of the former Fuel Farm and Building G480. The results of the RI indicate that Area 1 was located in an area with surficial groundwater contamination that exceeded 1,000 ug/L of total fuel-related contamination (upper portion of the surficial aquifer). However, during this investigation no fuel-related contamination was detected in the surficial aquifer within the limits of Area 1.
- Within the limits of Area 1 no substantial changes in the levels of solvent-related contamination occurred between April 1994 and February 1997. The levels of total solvent related contamination within the limits of Area 1 detected during this investigation are generally consistent with the RI results.
- Based on the levels of total solvent-related contamination and the extent of contamination, Area 1 is a sufficient location for the installation of an IAS system but not the optimal location. Although contamination is present in Area 1, the optimal location for the IAS system would be in the area with the highest and most widespread levels of total solvent-related contamination. The maximum level of total solvent-related contamination within the limits of Area 1 (298 ug/L) is substantially lower than the maximum level observed within the limits of Area 2 (886 ug/L). Total solvent-related contamination is limited to the lower portion of the lower portion of the surficial aquifer within the limits of Area 1. Total solvent-related contamination was observed in the upper and lower portions of the surficial aquifer within the limits of Area 2.
- No substantial clay layer or strata that could potentially impact the design and implementation of the IAS system were identified above the Castle Hayne confining unit in Area 1.
- The top of the Castle Hayne confining unit is approximately 44 feet bgs within Area 1.
- No substantial clay layer was identified above the Castle Hayne confining unit in Area 1.

#### Area 2

- The implementation of Phase I construction activities could potentially be delayed if Area 2 is selected as the proposed location. The commencement date of bypass demolition activities in Area 2 is somewhat uncertain. The implementation of Phase I construction Activities will require the removal of Buildings TC-473 and TC-474, and associated parking facilities.
- Within the limits of Area 2 limited changes in the levels of solvent-related contamination occurred between April 1994 and February 1997. The levels of total solvent related contamination within the limits of Area 2 detected during this investigation are generally consistent with the RI results with two exceptions. Monitoring well TW36A exhibited 148 ug/L of total solvent-related contamination but a detection of over 1000 ug/L was anticipated based on RI data. Monitoring well TW36A exhibited 600 ug/L of total solvent-related contamination. However, no contamination was anticipated at this location.
- Fuel related contamination in the surficial aquifer, within the limits of Area 2, has been potentially been impacted by the removal of petroleum contaminated soils in the vicinity of the former Fuel Farm and Building G480. The results of the RI indicate that Area 2 was located in an area with surficial groundwater contamination that exceeded 100 ug/L of total fuel-related contamination (upper and lower portion of the surficial aquifer). However, during this investigation fuel-related contamination was limited to a single detection of xylenes (5 ug/L) in the surficial aquifer within the limits of Area 2.

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- Based on the levels of total solvent-related contamination and the extent of contamination, Area 2 is the optimal location for the installation of the IAS system. The optimal location for the IAS system is in the area with the highest and most widespread levels of total solvent-related contamination. The maximum level of total solvent-related contamination within the limits of Area 2 (886 ug/L ) is substantially higher than the maximum level observed within the limits of Area 1 (289 ug/L). Total solvent-related contamination was observed in the upper and lower portions of the surficial aquifer within the limits of Area 2. However, total solvent-related contamination is limited to the lower portion of the lower portion of the surficial aquifer within the limits of Area 1.
- No substantial clay layer or strata that could potentially impact the design and implementation of the IAS were identified above the Castle Hayne confining unit in Area 2.
- The top of the Castle Hayne confining unit is approximately 41 to 45 feet bgs within Area 2.
- No substantial clay layer was identified above the Castle Hayne confining unit in Area 2.

#### RECOMMENDATION

Based on the data obtained from the field investigation and background information, Baker recommends that Phase I construction activities be implemented in Area 1 as proposed in the 100% Design Package.

Baker appreciates the opportunity to serve LANTDIV on this project. If you have any questions please do not hesitate to contact me at (412) 269-2063 or Mr. Matthew D. Bartman, Baker Activity Coordinator at (412) 269-2063.

Sincerely,

BAKER ENVIRONMENTAL, INC.



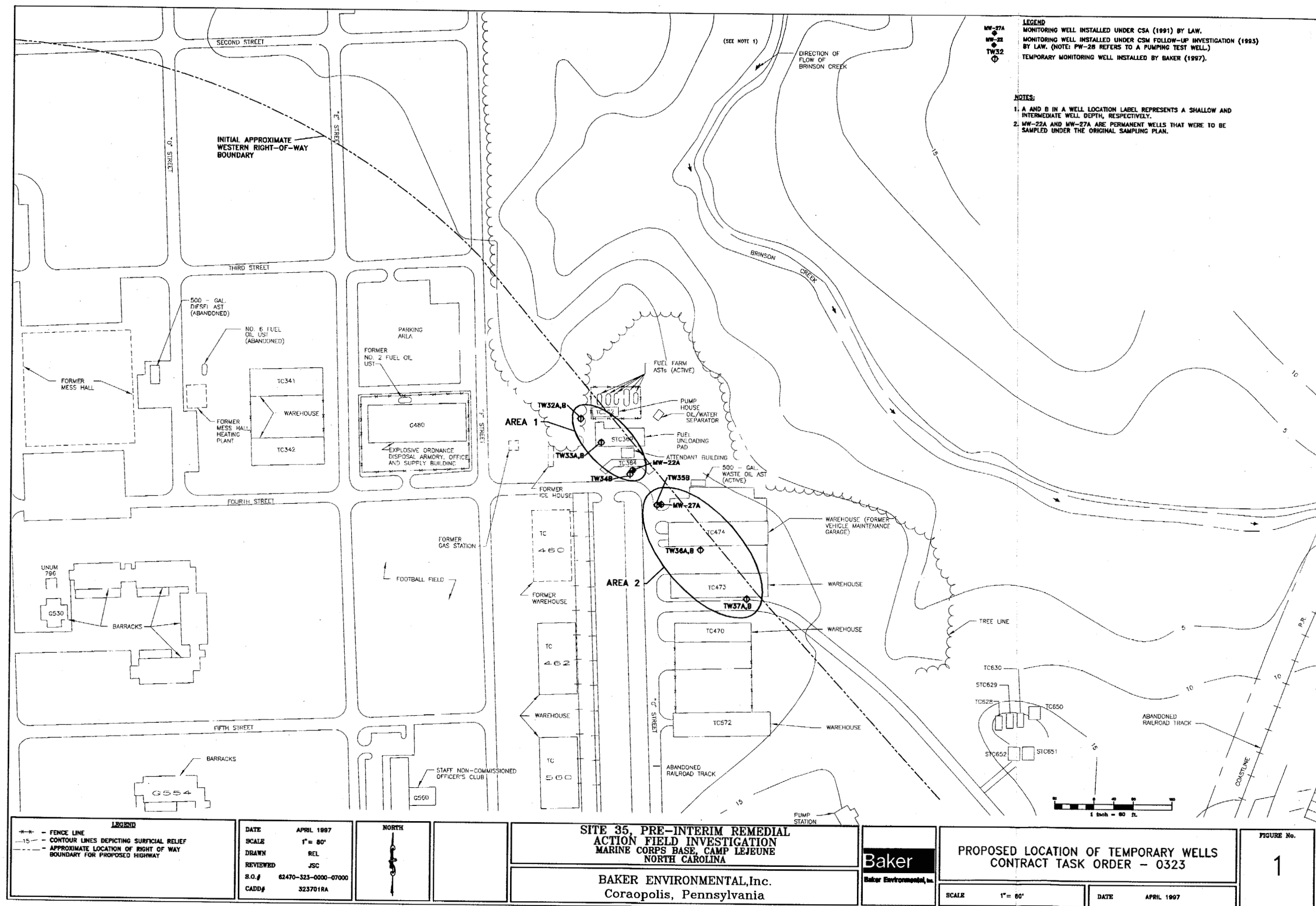
Daniel L. Bonk, P.E.  
Project Manager

DLB/MDS/lq  
Attachments

cc: Ms. Lee Anne Rapp, P.E., LANTDIV, Code 18312 (w/o attachments)  
Mr. Neal Paul, Camp Lejeune

**ATTACHMENT A**  
**FIGURES**

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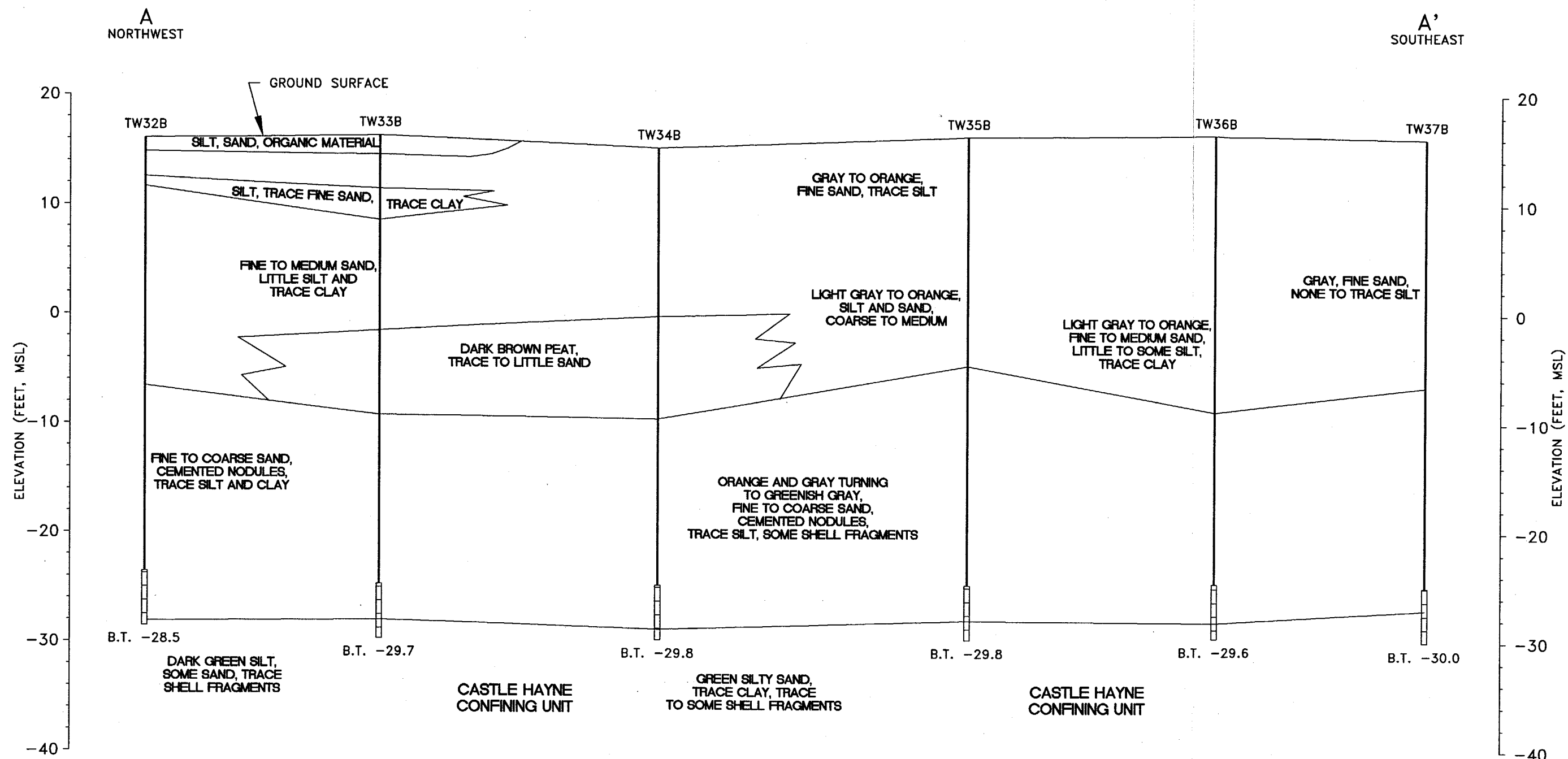


01756 DDB32








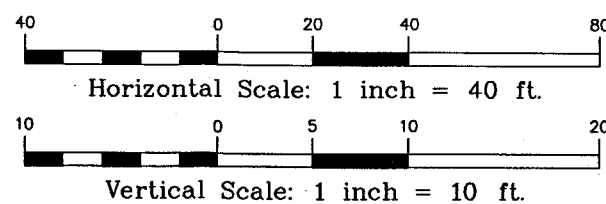



**Baker**

Baker Environmental, Inc.

**LEGEND**

- B.T. -28.5' BORING TERMINATED, ELEVATION MSL  
 WELL SCREEN INTERVAL  
 ESTIMATED SOIL CONTACT  
 PROJECTED SOIL CONTACT



THE SOIL BORING INFORMATION IS CONSIDERED TO BE REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE RESPECTIVE BORING LOCATIONS. SUBSURFACE CONDITIONS INTERPOLATED BETWEEN BORINGS ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND GEOLOGIC JUDGEMENT.

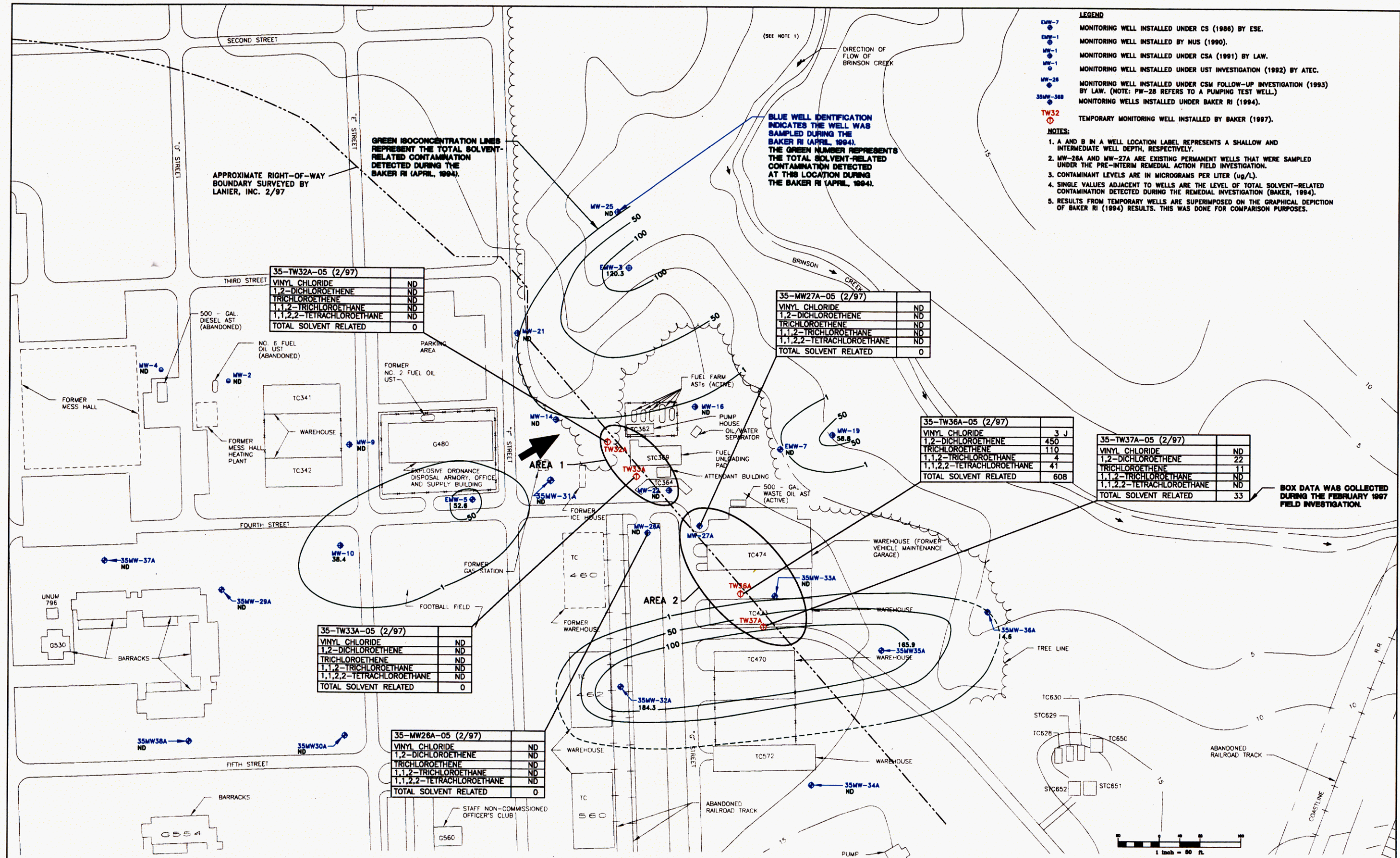
**FIGURE 4**  
**GEOLOGIC CROSS-SECTION A-A'**  
**SITE 35, PRE-INTERIM REMEDIAL ACTION**  
**FIELD INVESTIGATION**  
**CONTRACT TASK ORDER - 0323**

MARINE CORPS BASE, CAMP LEJEUNE  
 NORTH CAROLINA









- LEGEND**
- EMW-7
  - EMW-1
  - MW-1
  - MW-1
  - MW-28
  - 35MW-368
  - TW32
- MONITORING WELL INSTALLED UNDER CS (1986) BY ESE.  
MONITORING WELL INSTALLED BY NUS (1990).  
MONITORING WELL INSTALLED UNDER CSA (1991) BY LAW.  
MONITORING WELL INSTALLED UNDER UST INVESTIGATION (1992) BY ATEC.  
MONITORING WELL INSTALLED UNDER CSM FOLLOW-UP INVESTIGATION (1993) BY LAW. (NOTE: PW-28 REFERS TO A PUMPING TEST WELL.)  
MONITORING WELLS INSTALLED UNDER BAKER RI (1994).  
TEMPORARY MONITORING WELL INSTALLED BY BAKER (1997).

- NOTES:**
1. A AND B IN A WELL LOCATION LABEL REPRESENTS A SHALLOW AND INTERMEDIATE WELL DEPTH, RESPECTIVELY.
  2. MW-28A AND MW-27A ARE EXISTING PERMANENT WELLS THAT WERE SAMPLED UNDER THE PRE-INTERIM REMEDIAL ACTION FIELD INVESTIGATION.
  3. CONTAMINANT LEVELS ARE IN MICROGRAMS PER LITER (ug/L).
  4. SINGLE VALUES ADJACENT TO WELLS ARE THE LEVEL OF TOTAL SOLVENT-RELATED CONTAMINATION DETECTED DURING THE REMEDIAL INVESTIGATION (BAKER, 1994).
  5. RESULTS FROM TEMPORARY WELLS ARE SUPERIMPOSED ON THE GRAPHICAL DEPICTION OF BAKER RI (1994) RESULTS. THIS WAS DONE FOR COMPARISON PURPOSES.

35-TW32A-05 (2/97)	
VINYL CHLORIDE	ND
1,2-DICHLOROETHENE	ND
TRICHLOROETHENE	ND
1,1,2-TRICHLOROETHANE	ND
1,1,2,2-TETRACHLOROETHANE	ND
TOTAL SOLVENT RELATED	0

35-MW27A-05 (2/97)	
VINYL CHLORIDE	ND
1,2-DICHLOROETHENE	ND
TRICHLOROETHENE	ND
1,1,2-TRICHLOROETHANE	ND
1,1,2,2-TETRACHLOROETHANE	ND
TOTAL SOLVENT RELATED	0

35-TW36A-05 (2/97)	
VINYL CHLORIDE	3 J
1,2-DICHLOROETHENE	450
TRICHLOROETHENE	110
1,1,2-TRICHLOROETHANE	4
1,1,2,2-TETRACHLOROETHANE	41
TOTAL SOLVENT RELATED	608

35-TW37A-05 (2/97)	
VINYL CHLORIDE	ND
1,2-DICHLOROETHENE	22
TRICHLOROETHENE	11
1,1,2-TRICHLOROETHANE	ND
1,1,2,2-TETRACHLOROETHANE	ND
TOTAL SOLVENT RELATED	33

35-TW33A-05 (2/97)	
VINYL CHLORIDE	ND
1,2-DICHLOROETHENE	ND
TRICHLOROETHENE	ND
1,1,2-TRICHLOROETHANE	ND
1,1,2,2-TETRACHLOROETHANE	ND
TOTAL SOLVENT RELATED	0

35-MW26A-05 (2/97)	
VINYL CHLORIDE	ND
1,2-DICHLOROETHENE	ND
TRICHLOROETHENE	ND
1,1,2-TRICHLOROETHANE	ND
1,1,2,2-TETRACHLOROETHANE	ND
TOTAL SOLVENT RELATED	0

**LEGEND**

- - - FENCE LINE
- 15- CONTOUR LINES DEPICTING SURFICIAL RELIEF
- 50- ISOCONCENTRATION LIMITS OF COMBINED HALOGENATED ORGANICS FROM 4/94.
- - - APPROXIMATE LOCATION OF RIGHT OF WAY BOUNDARY FOR PROPOSED HIGHWAY
- ➔ APPROXIMATE GROUNDWATER FLOW DIRECTION

DATE: APRIL 1997  
SCALE: 1" = 80'  
DRAWN: WJH/REL  
REVIEWED: MDS  
S.O.#: 62470-323-0000-07000  
CADD#: 323705RA

NORTH

**SITE 35, PRE-INTERIM REMEDIAL ACTION FIELD INVESTIGATION**  
MARINE CORPS BASE, CAMP LEJEUNE  
NORTH CAROLINA

**BAKER ENVIRONMENTAL, Inc.**  
Coraopolis, Pennsylvania

**Baker**  
Baker Environmental, Inc.

**COMPARISON OF SOLVENT-RELATED CONTAMINATION IN THE UPPER PORTION OF THE SURFICIAL AQUIFER, FEB. 1997 AND APRIL 1994**  
CONTRACT TASK ORDER - 0323

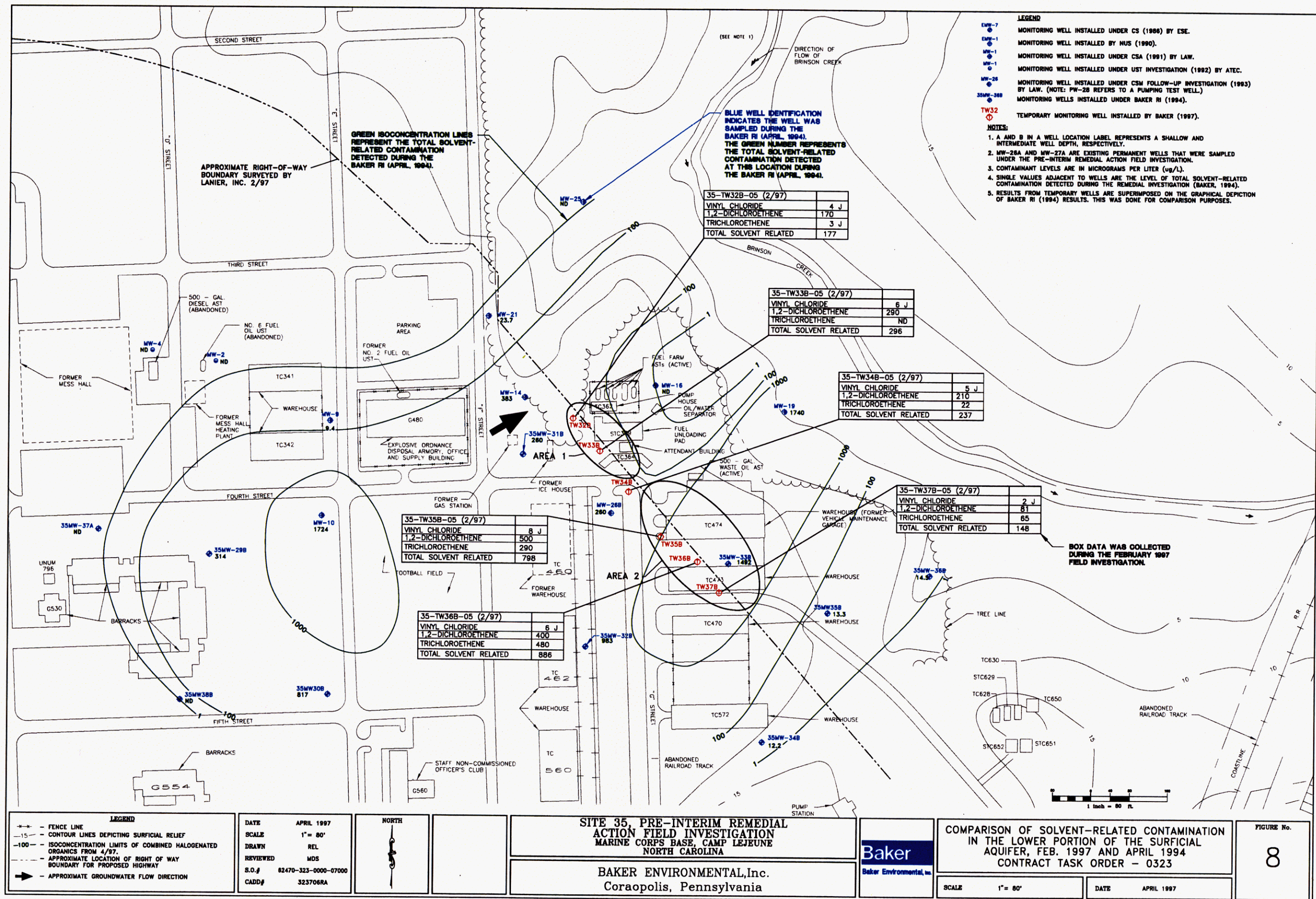
SCALE: 1" = 80'  
DATE: APRIL 1997

FIGURE No.  
**6**









**ATTACHMENT B**  
**TABLES**

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**TABLE 1**

**TEMPORARY WELL CONSTRUCTION DATA  
PRE-INTERIM REMEDIAL ACTION FIELD INVESTIGATION  
SITE 35, CAMP GEIGER AREA FUEL FARM  
CONTRACT TASK ORDER 0323**

<b>Monitoring Well</b>	<b>Date Constructed</b>	<b>Well Depth feet bgs</b>	<b>Screened feet bgs from</b>	<b>Interval feet bgs to</b>
<b>Shallow Temporary Wells</b>				
35-TW32A	3/24/97	17.5	7.5	17.5
35-TW33A	3/24/97	16	6	16
35-TW36A	3/25/97	18	8	18
35-TW37A	3/26/97	17	7	17
<b>Intermediate Temporary Wells</b>				
35-TW32B	3/24/97	46	41	46
35-TW33B	3/24/97	46	41	46
35-TW34B	3/25/97	45	40	45
35-TW35B	3/25/97	46	41	46
35-TW36B	3/25/97	45	40	45
35-TW37B	3/25/97	46	41	46

TABLE 2

VOLATILE ORGANIC CONTAMINATION  
PRE-INTERIM REMEDIAL ACTION FIELD INVESTIGATION  
SITE 35, CAMP GEIGER AREA FUEL FARM  
MCB, CAMP LEJEUNE  
CONTRACT TASK ORDER 0323

Compound	Well Number and Date Sampled											
	35-TW32A-05 2/25/97	35-TW32B-05 2/25/97	35-TW33A-05 2/25/97	35-TW33B-05 2/25/97	35-TW34B-05 2/26/97	35-TW35B-05 2/26/97	35-TW36A-05 2/26/97	35-TW36B-05 2/26/97	35-TW37A-05 2/26/97	35-TW37B-05 2/26/97	35-MW26A-05 2/27/97	35-MW27A-05 2/27/97
Vinyl Chloride	ND	4J	ND	6J	5J	8J	3J	6J	ND	2J	ND	ND
1,2-Dichloroethene (total)	ND	170	ND	290	210	500	450	400	22	81	ND	ND
Chloroform	ND	ND	2J	ND	ND	3J	6J	ND	ND	ND	ND	ND
Bromodichloromethane	ND	ND	ND	ND	ND	3J	4J	ND	ND	ND	ND	ND
Trichloroethene	ND	3J	ND	ND	22	290	110	480	11	65	ND	ND
1,1,2-Trichloroethane	ND	ND	ND	ND	ND	ND	4J	ND	ND	ND	ND	ND
1,1,2,2-Tetrachlorethane	ND	ND	ND	ND	ND	ND	41	ND	ND	ND	ND	ND
Xylene (total)	ND	ND	ND	ND	ND	ND	4J	ND	ND	ND	ND	ND

## Footnotes:

ND = Non Detection

J = Estimated Quantity

All Concentrations are in  $\mu\text{g/L}$ .

ATTACHMENT C  
LABORATORY DATA AND CHAIN-OF-CUSTODY SHEETS



RFW Batch Number: 9702G273

Client: Baker-Lejeune #323

Work Order: 0000-00-0

Page: 1a

Cust ID: 35-TW32A-05 35-TW32B-05 35-TW33A-05 35-TW33B-05 35-TW33B-05 35-TW35B-05

Sample Information	RFW#:	001	002	003	004	004 DL	005
Matrix:		WATER	WATER	WATER	WATER	WATER	WATER
D.F.:		1	1	1	1	10	1
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,2-Dichloroethane-d4		93 %	95 %	95 %	92 %	94 %	90 %
Surrogate Toluene-d8		97 %	97 %	97 %	103 %	99 %	95 %
Recovery 4-Bromofluorobenzene		91 %	97 %	98 %	99 %	98 %	91 %
Chloromethane		10 U	10 U	10 U	10 U	100 U	10 U
Bromomethane		10 U	10 U	10 U	10 U	100 U	10 U
Vinyl chloride		10 U	4 J	10 U	6 J	100 U	8 J
Chloroethane		10 U	10 U	10 U	10 U	100 U	10 U
Methylene Chloride		10 U	10 U	10 U	10 U	100 U	10 U
Acetone		10 U	10 U	10 U	10 U	100 U	10 U
Carbon Disulfide		10 U	10 U	10 U	10 U	100 U	10 U
1,1-Dichloroethene		10 U	10 U	10 U	10 U	100 U	10 U
1,1-Dichloroethane		10 U	10 U	10 U	10 U	100 U	10 U
1,2-Dichloroethene (total)		10 U	170	10 U	220 E	290 D	420 E
Chloroform		10 U	10 U	2 J	10 U	100 U	3 J
1,2-Dichloroethane		10 U	10 U	10 U	10 U	100 U	10 U
2-Butanone		10 U	10 U	10 U	10 U	100 U	10 U
1,1,1-Trichloroethane		10 U	10 U	10 U	10 U	100 U	10 U
Carbon Tetrachloride		10 U	10 U	10 U	10 U	100 U	10 U
Bromodichloromethane		10 U	10 U	10 U	10 U	100 U	3 J
1,2-Dichloropropane		10 U	10 U	10 U	10 U	100 U	10 U
cis-1,3-Dichloropropene		10 U	10 U	10 U	10 U	100 U	10 U
Trichloroethene		10 U	3 J	10 U	10 U	100 U	210 E
Dibromochloromethane		10 U	10 U	10 U	10 U	100 U	10 U
1,1,2-Trichloroethane		10 U	10 U	10 U	10 U	100 U	10 U
Benzene		10 U	10 U	10 U	10 U	100 U	10 U
trans-1,3-Dichloropropene		10 U	10 U	10 U	10 U	100 U	10 U
Bromoform		10 U	10 U	10 U	10 U	100 U	10 U
4-Methyl-2-pentanone		10 U	10 U	10 U	10 U	100 U	10 U
2-Hexanone		10 U	10 U	10 U	10 U	100 U	10 U
Tetrachloroethene		10 U	10 U	10 U	10 U	100 U	10 U
1,1,2,2-Tetrachloroethane		10 U	10 U	10 U	10 U	100 U	10 U
Toluene		10 U	10 U	10 U	10 U	100 U	10 U

\*= Outside of EPA CLP QC Limits.

RfW Ba

Number: 9702G273

Client: Baker-Lejeune #

Work Order: 0000-00-0

Page: 1b

Cust ID: 35-TW32A-05 35-TW32B-05

35-TW33A-05 35-TW33B-05 35-TW33B-05 35-TW35L

11

RfW#:	001	002	003	004	004 DL	005
Chlorobenzene	10 U	10 U	10 U	10 U	100 U	10 U
Ethylbenzene	10 U	10 U	10 U	10 U	100 U	10 U
Styrene	10 U	10 U	10 U	10 U	100 U	10 U
Xylene (total)	10 U	10 U	10 U	10 U	100 U	10 U

\*= Outside of EPA CLP QC limits.

RFW Batch Number: 9702G273

Client: Baker-Lejeune #323

Work Order: 0000-00-0

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Cust ID: 35-TW35B-05

35-TW36A-05

35-TW36A-05

35-RB01-05

35-TB01-05

35-TB02-05

Sample Information	RFW#:	005 DL	006	006 DL	007	008	009
	Matrix:	WATER	WATER	WATER	WATER	WATER	WATER
	D.F.:	10	1	10	1	1	1
	Units:	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Surrogate	1,2-Dichloroethane-d4	95 %	91 %	99 %	95 %	96 %	94 %
	Toluene-d8	99 %	98 %	106 %	100 %	100 %	100 %
Recovery	4-Bromofluorobenzene	102 %	94 %	101 %	92 %	95 %	98 %
=====f=====		f	f	f	f	f	f
Chloromethane		100 U	10 U	100 U	10 U	10 U	10 U
Bromomethane		100 U	10 U	100 U	10 U	10 U	10 U
Vinyl chloride		100 U	3 J	100 U	10 U	10 U	10 U
Chloroethane		100 U	10 U	100 U	10 U	10 U	10 U
Methylene Chloride		100 U	10 U	100 U	10 U	10 U	10 U
Acetone		100 U	10 U	100 U	10 U	10 U	10 U
Carbon Disulfide		100 U	10 U	100 U	10 U	10 U	10 U
1,1-Dichloroethene		100 U	10 U	100 U	10 U	10 U	10 U
1,1-Dichloroethane		100 U	10 U	100 U	10 U	10 U	10 U
1,2-Dichloroethene (total)		500 D	380 E	450 D	10 U	10 U	10 U
Chloroform		100 U	6 J	100 U	10 U	10 U	10 U
1,2-Dichloroethane		100 U	10 U	100 U	10 U	10 U	10 U
2-Butanone		100 U	10 U	100 U	10 U	10 U	10 U
1,1,1-Trichloroethane		100 U	10 U	100 U	10 U	10 U	10 U
Carbon Tetrachloride		100 U	10 U	100 U	10 U	10 U	10 U
Bromodichloromethane		100 U	4 J	100 U	10 U	10 U	10 U
1,2-Dichloropropane		100 U	10 U	100 U	10 U	10 U	10 U
cis-1,3-Dichloropropene		100 U	10 U	100 U	10 U	10 U	10 U
Trichloroethene		290 D	110	100 U	10 U	10 U	10 U
Dibromochloromethane		100 U	10 U	100 U	10 U	10 U	10 U
1,1,2-Trichloroethane		100 U	4 J	100 U	10 U	10 U	10 U
Benzene		100 U	10 U	100 U	10 U	10 U	10 U
trans-1,3-Dichloropropene		100 U	10 U	100 U	10 U	10 U	10 U
Bromoform		100 U	10 U	100 U	10 U	10 U	10 U
4-Methyl-2-pentanone		100 U	10 U	100 U	10 U	10 U	10 U
2-Hexanone		100 U	10 U	100 U	10 U	10 U	10 U
Tetrachloroethene		100 U	10 U	100 U	10 U	10 U	10 U
1,1,2,2-Tetrachloroethane		100 U	41	100 U	10 U	10 U	10 U
Toluene		100 U	10 U	100 U	10 U	10 U	10 U

\*= Outside of EPA CLP QC limits.

RfW#:	005 DL	006	006 DL	007	008	009
Chlorobenzene	100 U	10 U	100 U	10 U	10 U	10 U
Ethylbenzene	100 U	10 U	100 U	10 U	10 U	10 U
Styrene	100 U	10 U	100 U	10 U	10 U	10 U
Xylene (total)	100 U	4 J	100 U	10 U	10 U	10 U

\*= Outside of EPA CLP QC limits.

RFW Batch Number: 9702G273

Client: Baker-Lejeune #323

Work Order: 0000-00-0

Page: 3a

Cust ID: 35-TW36B-05 35-TW36B-05 35-TW36B-05 35-TW36B-05 35-TW36BD-05 35-TW36BD-05

Sample Information	RFW#:	010	010 DL	010 MS	010 MSD	011	011 DL
Matrix:		WATER	WATER	WATER	WATER	WATER	WATER
D.F.:		1	10	1	1	1	10
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,2-Dichloroethane-d4		91 %	103 %	93 %	95 %	94 %	99 %
Surrogate Toluene-d8		103 %	91 %	99 %	102 %	97 %	96 %
Recovery 4-Bromofluorobenzene		96 %	97 %	103 %	96 %	97 %	101 %
Chloromethane		10 U	100 U	10 U	10 U	10 U	100 U
Bromomethane		10 U	100 U	10 U	10 U	10 U	100 U
Vinyl chloride		6 J	100 U	5 J	6 J	5 J	100 U
Chloroethane		10 U	100 U	10 U	10 U	10 U	100 U
Methylene Chloride		10 U	100 U	10 U	10 U	10 U	100 U
Acetone		10 U	100 U	10 U	10 U	10 U	100 U
Carbon Disulfide		10 U	100 U	10 U	10 U	10 U	100 U
1,1-Dichloroethene		10 U	100 U	114 %	129 %	10 U	100 U
1,1-Dichloroethane		10 U	100 U	10 U	10 U	10 U	100 U
1,2-Dichloroethene (total)		350 E	400 D	340	350	320 E	380 D
Chloroform		10 U	100 U	10 U	10 U	10 U	100 U
1,2-Dichloroethane		10 U	100 U	10 U	10 U	10 U	100 U
2-Butanone		10 U	100 U	10 U	10 U	10 U	100 U
1,1,1-Trichloroethane		10 U	100 U	10 U	10 U	10 U	100 U
Carbon Tetrachloride		10 U	100 U	10 U	10 U	10 U	100 U
Bromodichloromethane		10 U	100 U	10 U	10 U	10 U	100 U
1,2-Dichloropropane		10 U	100 U	10 U	10 U	10 U	100 U
cis-1,3-Dichloropropene		10 U	100 U	10 U	10 U	10 U	100 U
Trichloroethene		390 E	480 D	91 %	78 %	360 E	460 D
Dibromochloromethane		10 U	100 U	10 U	10 U	10 U	100 U
1,1,2-Trichloroethane		10 U	100 U	10 U	10 U	10 U	100 U
Benzene		10 U	100 U	117 %	110 %	10 U	100 U
trans-1,3-Dichloropropene		10 U	100 U	10 U	10 U	10 U	100 U
Bromoform		10 U	100 U	10 U	10 U	10 U	100 U
4-Methyl-2-pentanone		10 U	100 U	10 U	10 U	10 U	100 U
2-Hexanone		10 U	100 U	10 U	10 U	10 U	100 U
Tetrachloroethene		10 U	100 U	10 U	10 U	10 U	100 U
1,1,2,2-Tetrachloroethane		10 U	100 U	10 U	10 U	10 U	100 U
Toluene		10 U	100 U	108 %	107 %	10 U	100 U

\*= Outside of EPA CLP QC limits.

RfW Bat

Number: 9702G273

Client: Baker-Lejeune #37

Work Order: 0000-00-0

Page: 3b

Cust ID: 35-TW36B-05 35-TW36B-05

TW36B-05 35-TW36B-05 35-TW36BD-05 35-TW36B

15

RfW#:	010	010 DL	010 MS	010 MSD	011	011 DL
Chlorobenzene	10 U	100 U	106 %	102 %	10 U	100 U
Ethylbenzene	10 U	100 U	10 U	10 U	10 U	100 U
Styrene	10 U	100 U	10 U	10 U	10 U	100 U
Xylene (total)	10 U	100 U	10 U	10 U	10 U	100 U

\*= Outside of EPA CLP QC Limits.



Cust ID: 35-TW34B-05 35-TW37B-05 35-TW37A-05 35-TW37AD-05 35-IDW01-05 35-MW26A-05

Sample Information	RFW#:	012	013	014	015	016	017
	Matrix:	WATER	WATER	WATER	WATER	WATER	WATER
	D.F.:	1	1	1	1	1	1
	Units:	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1,2-Dichloroethane-d4		100 %	93 %	96 %	100 %	92 %	98 %
Toluene-d8		107 %	91 %	98 %	104 %	90 %	97 %
4-Bromofluorobenzene		105 %	94 %	96 %	100 %	90 %	97 %
Chloromethane		10 U	10 U	10 U	10 U	10 U	10 U
Bromomethane		10 U	10 U	10 U	10 U	10 U	10 U
Vinyl chloride		5 J	2 J	10 U	10 U	10 U	10 U
Chloroethane		10 U	10 U	10 U	10 U	10 U	10 U
Methylene Chloride		10 U	10 U	10 U	10 U	10 U	4 J
Acetone		10 U	10 U	10 U	10 U	10 U	10 U
Carbon Disulfide		10 U	10 U	10 U	10 U	10 U	10 U
1,1-Dichloroethene		10 U	10 U	10 U	10 U	10 U	10 U
1,1-Dichloroethane		10 U	10 U	10 U	10 U	10 U	10 U
1,2-Dichloroethene (total)		210	81	22	22	49	10 U
Chloroform		10 U	10 U	10 U	10 U	10 U	10 U
1,2-Dichloroethane		10 U	10 U	10 U	10 U	10 U	10 U
2-Butanone		10 U	10 U	10 U	10 U	10 U	10 U
1,1,1-Trichloroethane		10 U	10 U	10 U	10 U	10 U	10 U
Carbon Tetrachloride		10 U	10 U	10 U	10 U	10 U	10 U
Bromodichloromethane		10 U	10 U	10 U	10 U	10 U	10 U
1,2-Dichloropropane		10 U	10 U	10 U	10 U	10 U	10 U
cis-1,3-Dichloropropene		10 U	10 U	10 U	10 U	10 U	10 U
Trichloroethene		22	65	11	10 J	16	10 U
Dibromochloromethane		10 U	10 U	10 U	10 U	10 U	10 U
1,1,2-Trichloroethane		10 U	10 U	10 U	10 U	10 U	10 U
Benzene		10 U	10 U	10 U	10 U	10 U	10 U
trans-1,3-Dichloropropene		10 U	10 U	10 U	10 U	10 U	10 U
Bromoform		10 U	10 U	10 U	10 U	10 U	10 U
4-Methyl-2-pentanone		10 U	10 U	10 U	10 U	10 U	10 U
2-Hexanone		10 U	10 U	10 U	10 U	10 U	10 U
Tetrachloroethene		10 U	10 U	10 U	10 U	10 U	10 U
1,1,2,2-Tetrachloroethane		10 U	10 U	10 U	10 U	10 U	10 U
Toluene		10 U	10 U	10 U	10 U	10 U	10 U

\* = Outside of EPA CLP QC limits.

RFW Bat

Number: 9702G273

Client: Baker-Lejeune #3

Work Order: 0000-00-0

Page: 4b

Cust ID: 35-TW34B-05 35-TW37B-05

TW37A-05 35-TW37AD-05 35-IDW01-05 35-MW26A

RFW#:	012	013	014	015	016	017
Chlorobenzene	10 U	10 U	10 U	10 U	10 U	10 U
Ethylbenzene	10 U	10 U	10 U	10 U	10 U	10 U
Styrene	10 U	10 U	10 U	10 U	10 U	10 U
Xylene (total)	10 U	10 U	10 U	10 U	10 U	10 U

\*= Outside of EPA CLP QC Limits.

Cust ID: 35-MW27A-05

VBLKCF

VBLKCF BS

VBLKCH

VBLKCH BS

VBLKCJ

## Sample Information

```

RFW#:
Matrix:
D.F.:
Units:

```

018  
WATER  
1  
ug/L

97GVE087-MB1  
WATER  
1  
ug/L

97GVE087-MB1  
WATER  
1  
ug/L

97GVE088-MB1  
WATER 1  
ug/L

97GVE088-MB1  
WATER  
1  
ug/L

97GVE089-MB1  
WATER  
1  
ug/L

	1,2-Dichloroethane-d4	90	%	93	%	100	%	96	%	91	%	99	%
Surrogate	Toluene-d8	100	%	98	%	104	%	104	%	97	%	100	%
Recovery	4-Bromofluorobenzene	94	%	95	%	104	%	103	%	96	%	106	%
Chloromethane		10	U	10	U	10	U	10	U	10	U	10	U
Bromomethane		10	U	10	U	10	U	10	U	10	U	10	U
Vinyl chloride		10	U	10	U	10	U	10	U	10	U	10	U
Chloroethane		10	U	10	U	10	U	10	U	10	U	10	U
Methylene Chloride		10	U	10	U	10	U	10	U	10	U	10	U
Acetone		10	U	10	U	10	U	10	U	10	U	10	U
Carbon Disulfide		10	U	10	U	10	U	10	U	10	U	10	U
1,1-Dichloroethene		10	U	10	U	117	%	10	U	140	%	10	U
1,1-Dichloroethane		10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichloroethene (total)		10	U	10	U	10	U	10	U	10	U	10	U
Chloroform		10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichloroethane		10	U	10	U	10	U	10	U	10	U	10	U
2-Butanone		10	U	10	U	10	U	10	U	10	U	10	U
1,1,1-Trichloroethane		10	U	10	U	10	U	10	U	10	U	10	U
Carbon Tetrachloride		10	U	10	U	10	U	10	U	10	U	10	U
Bromodichloromethane		10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichloropropane		10	U	10	U	10	U	10	U	10	U	10	U
cis-1,3-Dichloropropene		10	U	10	U	10	U	10	U	10	U	10	U
Trichloroethene		10	U	10	U	97	%	10	U	107	%	10	U
Dibromochloromethane		10	U	10	U	10	U	10	U	10	U	10	U
1,1,2-Trichloroethane		10	U	10	U	10	U	10	U	10	U	10	U
Benzene		10	U	10	U	108	%	10	U	119	%	10	U
trans-1,3-Dichloropropene		10	U	10	U	10	U	10	U	10	U	10	U
Bromoform		10	U	10	U	10	U	10	U	10	U	10	U
4-Methyl-2-pentanone		10	U	10	U	10	U	10	U	10	U	10	U
2-Hexanone		10	U	10	U	10	U	10	U	10	U	10	U
Tetrachloroethene		10	U	10	U	10	U	10	U	10	U	10	U
1,1,2,2-Tetrachloroethane		10	U	10	U	10	U	10	U	10	U	10	U
Toluene		10	U	10	U	108	%	10	U	110	%	10	U

\*= Outside of EPA CLP QC limits.

RfW Bat

Number: 9702G273

Client: Baker-Lejeune #3

Work Order: 0000-00-0

Page: 5b

Cust ID: 35-MW27A-05 VBLKCF

VBLKCF BS

VBLKCH

VBLKCH BS

VBLKCJ

RfW#:

018

97GVE087-MB1

97GVE087-MB1

97GVE088-MB1

97GVE088-MB1

97GVE089-MB1

Chlorobenzene	10	U	10	U	102	%	10	U	112	%	10	U
Ethylbenzene	10	U	10	U	10	U	10	U	10	U	10	U
Styrene	10	U	10	U	10	U	10	U	10	U	10	U
Xylene (total)	10	U	10	U	10	U	10	U	10	U	10	U

\*= Outside of EPA CLP QC limits.

61 19

Cust ID: VBLKCJ BS

Sample  
InformationRWF#: 97GVE089-MB1  
Matrix: WATER  
D.F.: 1  
Units: ug/L

Surrogate	1,2-Dichloroethane-d4	106	%
Recovery	Toluene-d8	101	%
	4-Bromofluorobenzene	107	%
=====f1=====f1=====f1=====f1=====f1=====			
Chloromethane		10	U
Bromomethane		10	U
Vinyl chloride		10	U
Chloroethane		10	U
Methylene Chloride		10	U
Acetone		10	U
Carbon Disulfide		10	U
1,1-Dichloroethene		138	%
1,1-Dichloroethane		10	U
1,2-Dichloroethene (total)		10	U
Chloroform		10	U
1,2-Dichloroethane		10	U
2-Butanone		10	U
1,1,1-Trichloroethane		10	U
Carbon Tetrachloride		10	U
Bromodichloromethane		10	U
1,2-Dichloropropane		10	U
cis-1,3-Dichloropropene		10	U
Trichloroethene		100	%
Dibromochloromethane		10	U
1,1,2-Trichloroethane		10	U
Benzene		115	%
trans-1,3-Dichloropropene		10	U
Bromoform		10	U
4-Methyl-2-pentanone		10	U
2-Hexanone		10	U
Tetrachloroethene		10	U
1,1,2,2-Tetrachloroethane		10	U
Toluene		106	%

\* = Outside of EPA CLP QC Limits.

RFW Ba Number: 9702G273 Client: Baker-Lejeune #2

Work Order: 0000-00-0

Page: 6b

Cust ID: VBLKCJ BS

RFW#: 97GVE089-MB1

Chlorobenzene	110	%
Ethylbenzene	10	U
Styrene	10	U
Xylene (total)	10	U

\*= Outside of EPA CLP QC limits.



381-596a



**ATTACHMENT D**  
**BORING LOGS**

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35-TW32B

2/24/97

DEPTH	SAMPLE	BLOWS	REL	PID
0-2	S-1	6-5-5-6	0.9	BG
2-4	S-2	7-8-8-8	1.0	BG
4-6	S-3	5-5-5-5	1.5	BG
6-8	S-4	5-3-3-3	2.0	BG
8-10	S-5	4-3-2-2	2.0	BG
10-12	S-6	3-2-2-3	1.5	BG
12-14	S-7	2-2-2-2	2.0	BG
14-16	S-8	3-3-8-9	1.1	BG
16-18	S-9	4-8-11-13	2.0	BG
18-20	S-10	6-8-13-13	2.0	BG
20-22	S-11	3-2-1-1	2.0	BG
22-24	S-12	10-6-6-11	1.2	BG

35-TW32B

## DESCRIPTION

GREY  
MED. DENSE, SAND, FINE GRAINED,  
TRACE SILT, DAMP 3.5  
MED. DENSE, BROWN, SILT, T. CLAY, T.  
SAND, DAMP 4.2  
MED. DENSE, GREY, SAND, FINE GRAINED,  
DAMP, GW @ 9.3' bgs 9.5  
LOOSE, ORANGE, SAND AND SILT, TRACE  
CLAY, WET.  
NOTE: SAND IS MED. GRAINED.  
NOTE: TRACE TO LITTLE SILT. 13.5  
LOOSE, GREY, SAND, FINE TO MED.  
GRAINED, L. SILT, T. CLAY, WET  
NOTE: NO SILT OR CLAY CONTENT.  
NOTE: LAST 0.25' - ORANGE LN  
COLOR  
NOTE: GREY LN COLOR  
NOTE: DK GREY LN COLOR 22.4  
MED. DENSE, GREY, SAND, FINE GRAINED,  
CEMENTED SAND NODULES, WET.

4/29/97

35-TW32B

DEPTH	SAMPLE	BLOWS	REC	PID
24-26	S-13	16-44-50/3	1.3	BG
26-28	S-14	22-22-14-31	1.9	BG
28-30	S-15	20-23-50/3	2.0	BG
30-32	S-16	28-18-16-33	2.0	BG
32-34	S-17	34-16-21-28	2.0	BG
34-36	S-18	12-10-12-16	1.5	BG
36-38	S-19	16-18-21-19	2.0	BG
38-40	S-20	19-15-15-15	2.0	BG
40-42	S-21	14-16-19-20	1.5	BG
42-44	S-22	29-38-50/4	1.5	BG

4/24/97

35-TW32B

## DESCRIPTION

SAME AS ABOVE

23.2

MED. DENSE, GREY, SAND, FINE GRAINED,  
LITTLE CLAY, TRAIL SILT, WET

23.9

MED. DENSE, GREY, SAND, FINE GRAINED,  
CEMENTED NODULES, SHELLS, WET

25.3

VERY DENSE, GREY, FINE SAND, T. CLAY,  
MOIST TO WET (CaCO<sub>3</sub> CEMENT)

29.5

VERY DENSE, GREY, SAND, MED. GRAINED,  
FEW NODULES, WET.

NOTE: NO. OF NODULES INCREASING.

SAA

NOTE: SILT &amp; CLAY CONTENT INCREASED

NOTE: SILT &amp; CLAY CONTENT DECREASED

NOTE: SAND IS FINE GRAINED

Very Dense @ 42.8, Damp



2/24/47

2/24/3

Depth	Sample	Blows	REL	PID
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44-46	S-23	7-8-7-8	1.5	BG
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DESCRIPTION

SAA

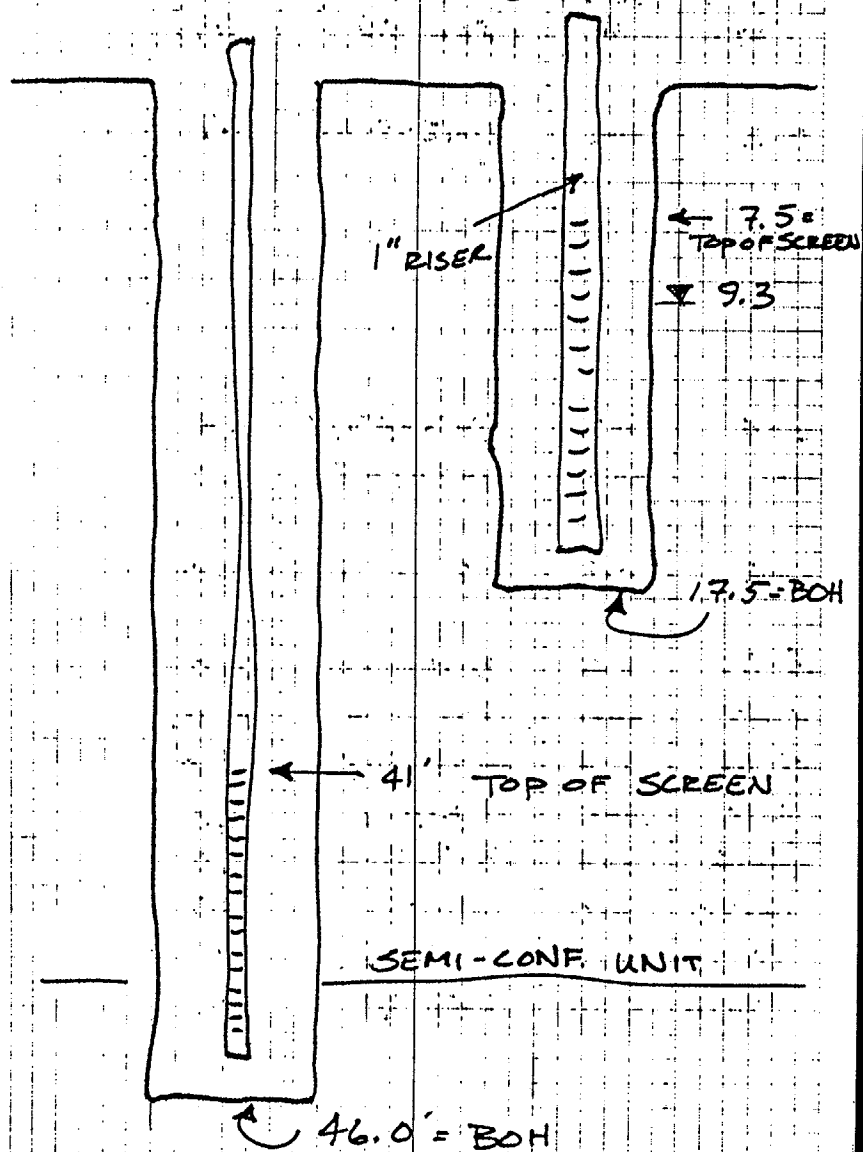
44.6

DK GREEN, SILT, SOME FINE  
SAND, MOIST

TD = 46.0'

35-TW32B

35-TW32A



4/24/97

PHASE I

35-TW33B

DEPTH (FT)	SAMPLE #	BLOWS (PER 0.5')	REC (FT)
0-2	S-1	5-12-12-10	1.7
2-4	S-2	9-7-5-5	1.3
4-6	S-3	1-2-1-2	2.0
6-8	S-4	1-2-4-5	2.0
8-10	S-5	3-4-4-4	2.0
10-12	S-6	3-3-4-4	N.R.
12-14	S-7	4-4-5-8	2.0
14-16	S-8	4-3-2-1	2.0
16-18	S-9	3-3-3-3	2.0
18-20	S-10	1-1-1-3	2.0
20-22	S-11	1-1-2-2	1.5
22-24	S-12	4-5-4-4	1.2

PHASE I

2/24/97

35-TW33B

DESCRIPTION

BEN, SAND, fine grained, L. SILT,  
damp  
0.4

DK BEN, SILT, ROOT MATERIAL (TRACE),  
L. SAND, DAMP

1.0  
BEN, SAND, fine grained, L. SILT, DAMP  
NOTE: GRAY

4.7  
BEN, SILT, T. SAND (FINE), MOIST

8.0 NOTE: GW @ 8'

GRAY, SAND, fine grained, Wet  
NOTE: TRACE SILT

NOTE: NO SILT

17.8

DK BEN, PEAT, Wet

NOTE: Sand Stringers @ 23.7' & 23.9', ea. Less  
than 0.5"

PHASE I

2/24/97

DEPT (FT)	Sample #	BLOWS (per 0.5')	REC. (FT)
24-26	S-13	6-8-5-5	1.8
26-28	S-14	2-2-1-1	2.0
28-30	S-15	2-2-1-1	2.0
30-32	S-16	1-1-26-30	2.0
32-34	S-17	26-39-50-6	0.5
34-36	S-18	17-20-15-16	1.4
36-38	S-19	16-20-29-39	2.0
38-40	S-20	36-21-21-40	2.0
40-42	S-21	8-18-26-27	0.7
42-44	S-22	28-32-45-35	1.9
44-46	S-23	5-6-7-9	2.0

DESCRIPTIONDK BEN, PEAT, WET  
25.0DK GREY, SILT and SAND, WET  
25.8ORANGE, SAND, T. SILT, WET

31.7

GREY, SAND, F-GRAINED, CEMENTED,  
SAND NODULES, S. Shell FRAGS, WET

NOTE: T. Clay

44.3

DK GREEN, SILT, some sand, T. Shells,  
MOIST.

TD = 46.0'

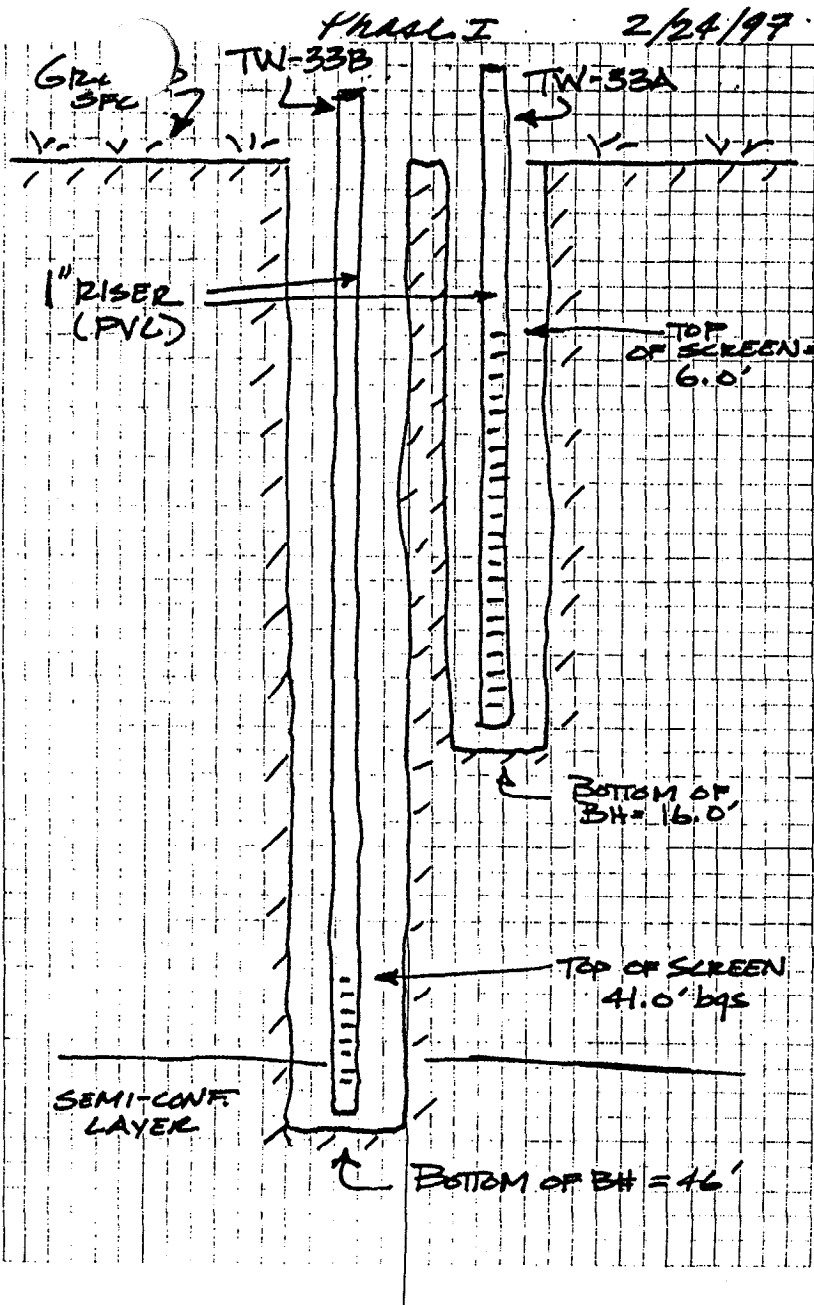
PHASE I

1/4/77

BLANK  
PAGE

PHASE I

2/24/97





4/25/97

CTD-323

35-TW348

Depth	Sample	BLOWS	REL	PID
4-6	S-1	4-5-9-9	1.4	BGD
9-11	S-2	3-3-2-4	0.8	BGD
14-16	S-3	2-2-2-2	1.8	BGD
19-21	S-4	4-5-5-4	1.8	BGD
24-26	S-5	9-18-38-16	1.9	BGD
29-31	S-6	19-19-19-24	1.6	BGD
34-36	S-7	11-18-18-20	1.4	BGD
38-40	S-8	22-16-16-33	1.8	BGD
40-42	S-9	14-14-14-22	1.9	BGD
42-44	S-10	42-46-32-29	2.0	BGD

HNU

KGROUND

CTD-323

2/25/97

## DESCRIPTION

LT. GREY, SAND (F-G), T. SILT, DAMP  
WELL SORTED, GWP 9.5'  
10.8 NOTE: @ 10' - POORLY SORTED, T. SILT  
ORANGE, DK GREY, SAND (F TO M-G),  
POORLY SORTED, T. & L. SILT, T. CLAY, WET  
12.5 - - - - -  
LT. BRN, SAND (M-G), MOD WELL SORTED,  
WET  
15.1  
DK GREY, SAND (F-G), W/ SILTY CLAY  
STRINGERS (ORANGE), WET.  
15.4 DK BRN, PEAT, WET  
22.5 - - - - -  
DK BRN, SAND, L. SILT, L. ORG. MATR, WET  
24.7 ORANGE TURNING LT GREY, SAND, PARTIALLY  
CEMENTED, NODULES, MED-FINE GRAINED,  
T. SILT, S. SHELL FRAGS, WET  
NOTE: GREENISH GRAY IN COLOR, T. CLAY  
43.8  
GREEN, SILTY SAND, F-GRAINED, T. CLAY,  
DAMP.

TD = 45.0'

CTD-323

DIAGRAM OF 35-TW333

3.25" H.S.A.

GROUND  
SFC

1" RISER

WELL SOCK

SEMICONE.  
UNIT

TOP OF SCREEN  
40'

5'

BOH = 45'

CTD-323

2/25/97

DIAGRAM OF  
35-TW353

3.25" H.S.A.

2" RISER

WELL  
SOCK

SEMICONE.  
UNIT

TOP OF SCREEN  
41'

5'

BOH = 46'

DEPTH	SAMPLE	BLOWS	REL	PID
		35-TW34B		
4-6	S-1	9-7-9-13	1.6	B6D
9-11	S-2	5-3-3-3	1.2	B6D
14-16	S-3	2-3-8-7	1.8	B6D
19-21	S-4	3-5-9-5	1.6	B6D
24-26	S-5	22-24-22-25	1.9	B6D
29-31	S-6	21-22-28-28	1.0	B6D
34-36	S-7	18-18-20-27	1.0	B6D
39-41	S-8	28-25-29-34	1.0	B6D
41-43	S-9	36-33-30-26	1.3	B6D
43-45	S-10	5-8-8-14	1.9	B6D
		46.0' = TD		

C10-323

2/25/97

HN.  
BGRD = 0.6 ppm

## DESCRIPTION

LT GREY, SAND, F-GRAINED, WELL SORTED,  
DAMP

7.5

Orange, SAND, L. SILT, MED-FINE GRAINED,  
WET. GR@B.O

10.7

GREY, SILT, SOME FINE SAND, L. CLAY,  
WET

12.5

GREY, SILT AND SAND, T. CLAY, WET

17.5

GREY, SAND, COARSE TO MED. GRAINED,  
MOD. WELL SORTED, WET.

20.7

Orange, SAND, FINE GRAINED, L. SILT,  
WELL SORTED, WET.

23.0

GREY, SAND, F-COARSE GRAINED, SOME  
SHELL FRAGS, T. SILT, WET, CEMENTED  
NODULES (CaCO<sub>3</sub>)

NOTE: GRAIN SIZE CHANGE TO FINE TO MED.

NOTE: Color Change to Greenish Grey.

44.2

GREEN, SILTY SAND, F-G, T. CLAY, MOD. ST,  
S. Shells.

35-TW36B

DEPTH	SAMPLE	BLANKS	REL	PID
4-6	S-1	4-4-4-4	2.0	BGD
9-11	S-2	1-2-2-1	2.0	BGD
14-16	S-3	2-2-2-4	2.0	BGD
19-21	S-4	3-4-5-3	2.0	BGD
24-26	S-5	15-20-26-34	2.0	BGD
29-31	S-6	17-56	1.0	BGD
34-36	S-7	32-39-29-22	0.9	BGD
39-41	S-8	15-16-28-27	1.3	BGD
41-43	S-9	26-38-36-26	2.0	BGD
43-45	S-10	8-7-8-6	2.0	BGD

HNA = 0.4 ppm

# DESCRIPTION

LT. GRAY, SAND, F-G, WELL SORTED,  
T. SILT, DAMP.

NOTE: GWC @ 10.0'

LT. GREY, SAND, F-G, WELL SORTED, S. SILT,  
T. CLAY, WET.

ORANGE, SAND, F-M GRAINED, L. SILT,  
WET

25.1

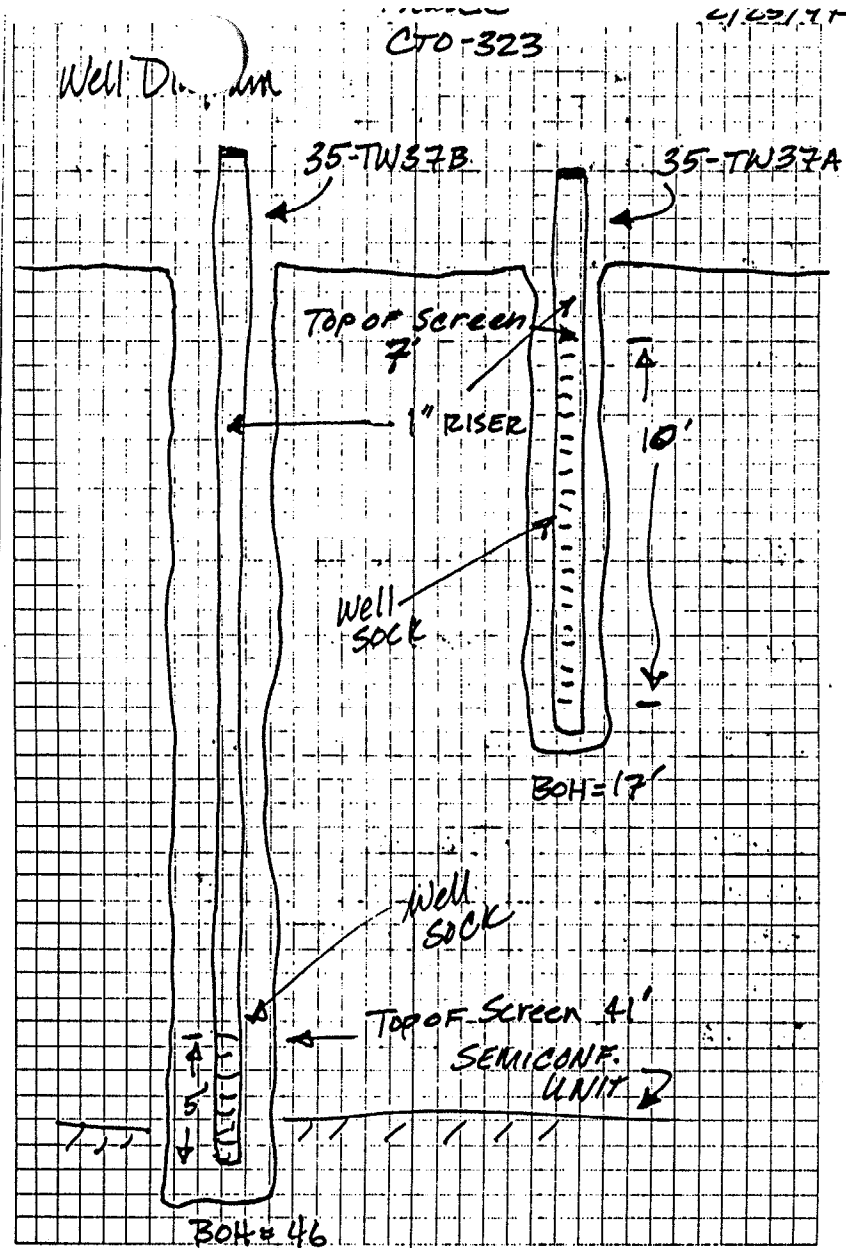
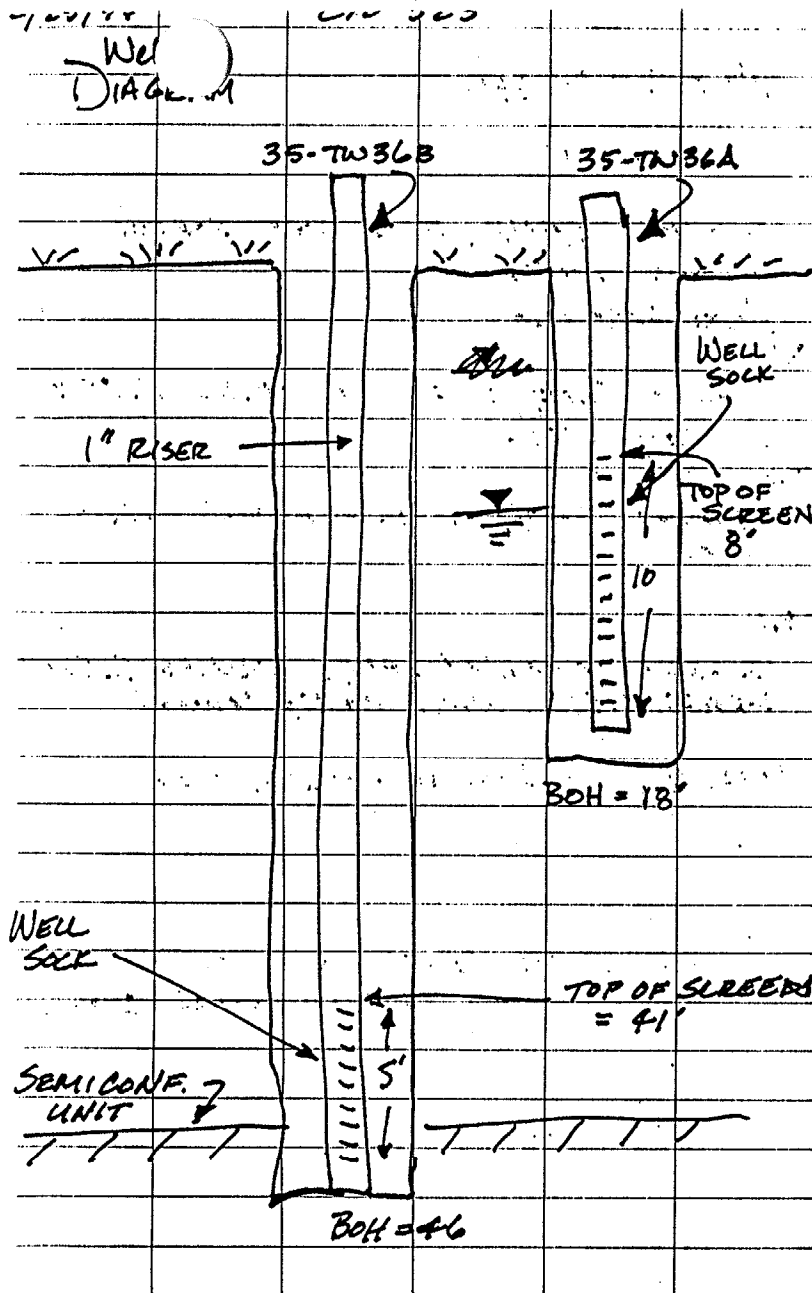
LT. GREY, CEMENTED SAND, NODULES, S. SHELL  
FRAGS, T. SILT, WET.  $\text{CaCO}_3$  CEMENT

NOTE: GREENISH GRAY IN COLOR, T. CLAY

44.6

GREEN, SAND, (F-G), WELL SORTED, S.  
SILT, T. CLAY, L. SHELL FRAGS, DAMP.

HG = 7.0





2/25/97

C10-323

35-TW37B

DEPTH	Sample	Blows	REL	PID
4-6	S-1	9-8-7-7	2.0	
9-11	S-2	4-3-4-4	2.0	
14-16	S-3	3-4-6-6	2.0	
19-21	S-4	1-0-1-0	2.0	
24-26	S-5	30-29-23-25	1.0	
29-31	S-6	57/6 inch.	0.6	
34-36	S-7	31-32-36-47	0.9	
39-41	S-8	18-30-42-47	0.5	
41-43	S-9	12-9-10-10	1.8	

C10-323

2/25/97

## DESCRIPTION

5.8  
LT GRAY, SAND, F-GRAINED, WELL SORTED, DAMP7.5  
Orange, SAND, F to MED. GRAINED, MOD. SORTED,  
T. SILT, DAMP.GW@9.0'  
GRAY, SAND, F-GRAINED, WELL  
SORTED, T. SILT, WET.15.2  
NOTE: FROM 14.8-15.2, Orange in color.

GRAY, SAND (F-G), WELL SORTED, WET.

22.5  
GRAY, concreted sand, F-coarse, poorly  
sorted, some shell frags, T. SILT,  
WET

NOTE: GREENISH GRAY IN COLOR, T. CLAY.

41.4

GREEN, SILTY SAND, Fine grained, Well  
Sorted, T. Shell fragments, Damp.

TD=43